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GUIDANCE MANUAL

FOR THE OPTIMIZATION OF

ONTARIO WATER TREATMENT PLANTS

USING THE COMPOSITE CORRECTION

PROGRAM (CCP) APPROACH

MAY 1998

Ontario

Ministry
of the
Environment

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1. INTRODUCTION

1.1 PURPOSE

This Ministry of the Environment (MOE) handbook has been developed to respond to the increasing need to improve performance at Ontario water treatment plants without incurring major expenses by upgrading or expanding treatment facilities. The United States Environmental Protection Agency (USEPA) Handbook entitled "Optimizing Water Treatment Plant Performance Using the Composite Correction Program" (1) was used as a platform for the writing of this document.

Several outbreaks of waterborne illness in Ontario, the other provinces, and the United States (U.S.) over the last few years, particularly with respect to *cryptosporidium* and *giardia* cysts, have refocused the need for optimized particle removal and disinfection at water treatment plants. Existing guidelines for turbidity and disinfection in Ontario were written before these pathogens became a concern, and may therefore not be adequate given the current state of knowledge (2,3,4). It is anticipated that more stringent guidelines regarding particulate removal and disinfection, including a concentration-time (Ct) analysis similar to USEPA's Surface Water Treatment Rule (SWTR) (5), will be introduced within the next few years in Ontario to provide an extra measure of certainty that pathogenic micro-organisms, if present in a water supply, are removed and/or inactivated to levels that will not cause a health concern.

Due to fiscal constraint, it will also be more difficult for the Ontario government and municipalities to fund the construction of water infrastructure at past levels. Optimization of existing facilities has the potential to improve the performance of water treatment plants to desired levels while deferring or eliminating the need for capital expenditures.

This MOE handbook presents procedures for identifying factors that cause poor performance in conventional and direct filtration plants, and outlines techniques used to address these factors and improve performance. Even though these procedures may identify design shortcomings, this MOE handbook is NOT a detailed process audit document to be used for studying facility expansion; it is a resource document to be used by consulting engineers and utilities wishing to improve the performance of existing water treatment facilities.

1.2 BACKGROUND

1.2.1 Wastewater

In the U.S., as a result of new regulations, many communities constructed new wastewater treatment facilities in the late 1960's and 1970's. After construction, monitoring indicated that many of these facilities were not in compliance with their discharge permits. A survey was conducted of over 100 facilities to identify the reasons for this non-compliance (6,7,8). The survey revealed that operations and maintenance factors were frequently identified as limiting plant performance, but also disclosed that administrative and design factors were contributing to poor plant performance. Additionally, each plant evaluated had a unique list of multiple factors limiting its performance.

Based on these findings, a program was developed to address performance limiting factors at an individual facility and to obtain improved performance. Significant success was achieved in improving performance at many wastewater treatment facilities without major capital improvements (9). Ultimately, a handbook was developed that formalized the evaluation as well as the correction procedures (10). This handbook was updated in 1989 to include specific low cost modifications that could be used to optimize an existing facility's performance (11).

The Composite Correction Program (CCP) approach, which is the name utilized for the formal procedures developed for wastewater, consists of two components, the Comprehensive Performance Evaluation (CPE) phase and the Comprehensive Technical Assistance (CTA) phase. A CPE is a thorough review and analysis of a plant's design capabilities and associated administrative, operation, and maintenance practices. It is conducted to identify factors that may be adversely impacting a plant's capability to achieve optimal performance. Its major objective is to determine if significant improvements in performance can be achieved without major capital improvements. A CTA is the performance improvement phase that is implemented if the results from the CPE indicate that improved performance can be achieved. During the CTA phase, identified factors are systematically eliminated. The major benefit of a CTA is that it optimizes the capability of existing facilities without the expense of major capital improvements.

1.2.2 Drinking Water

The State of Montana applied the CCP approach at most of the mechanical wastewater treatment facilities in the state. Results from these efforts showed dramatic improvement in compliance. These results led State personnel to initiate a program, with financial support from the USEPA, to evaluate the effectiveness of using the CCP approach at small drinking water treatment facilities using surface water supplies. From April 1988 until September 1990, nine CPEs and three CTAs were completed. Through these efforts each of the existing facilities where CTAs were implemented were brought into consistent compliance with the SWTR requirements for finished water turbidity. Additionally, improved performance was achieved at plants where only the evaluation phase (CPE) of the program was completed. These impacts on performance represented a definite improvement over the State's previous annual inspection program results. Other findings and benefits of the approach have been documented (12).

The USEPA's Office of Drinking Water has the responsibility of regulating U.S. water systems to assure that they produce drinking water that protects the public's health. To meet this objective a large number of drinking water regulations have been promulgated and all public water systems are expected to comply. Therefore, the USEPA was looking for cost-effective methods to achieve compliance. Based on the initial success of the Montana program, they decided to further develop and demonstrate the approach to ensure its applicability to other parts of the country. A cooperative project was initiated between USEPA's Office of Drinking Water, Technical Support Division (TSD) and Office of Technology Transfer and Regulatory Support, Center for Environmental Research Information (CERI). This project led to 12 additional CPEs in the states of Ohio, Kentucky, West Virginia, Maryland, Montana and Pennsylvania; the preparation of a summary report (13) to document the initial findings; and the development of the USEPA Handbook entitled "Optimizing Water Treatment Plant Performance Using the Composite Correction Program", on which this MOE handbook is based.

The USEPA handbook was written to help water utilities improve the performance of existing surface water treatment plants using conventional and direct filtration unit processes and achieve compliance with the SWTR. These plants are required to achieve at least 80 percent turbidity reduction or a finished water turbidity of 0.5 NTU, whichever is the lesser. In comparison, the Ontario Drinking Water Objectives (ODWO) specify a maximum acceptable turbidity of 1.0 NTU. The SWTR also requires that the total treatment processes achieve at least 99.9 percent (3-log) inactivation (via disinfection) and/or removal (via filtration) of *Giardia lamblia* cysts and at least 99.99 percent (4-log) inactivation and/or removal of viruses. The USEPA has published a guidance manual for the SWTR (14), that outlines procedures that are considered effective in assuring that the disinfection requirements are met. Cyst and virus removal credits for the different types of treatment processes are also provided in the SWTR guidance manual.

1.2.3 Ontario Experience

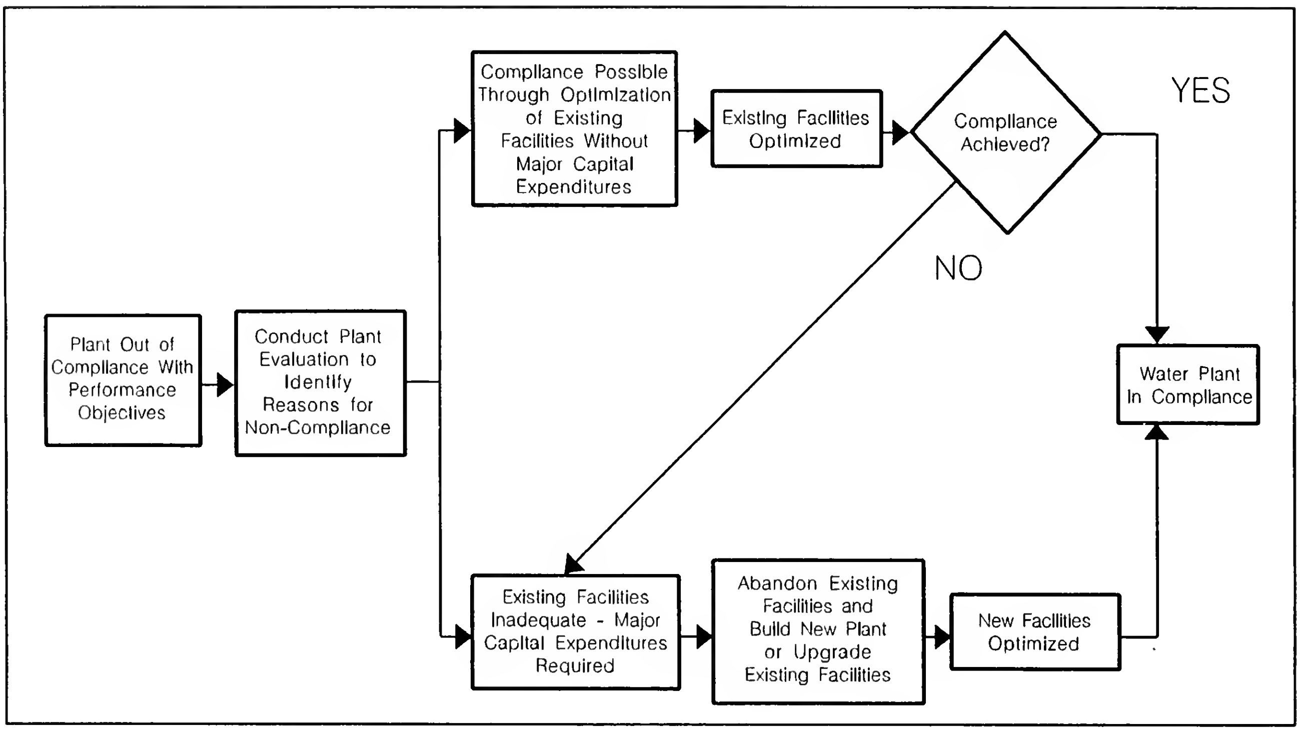
An MOE optimization study involving 40 water plants across Ontario was conducted from 1986-89. The emphasis in these studies was on documenting the physical facilities and operation of the plants. Follow-up on report recommendations was the responsibility of the municipality involved. Later, the MOE in partnership with Environment Canada, the Department of National Defense, Corrections Canada, and several regional municipalities conducted 15 CPEs and 7 CTAs at sewage treatment plants across Ontario starting in 1991. The findings were similar to the U.S. experience; substantial improvements in performance were achieved without major expenditures. Parts of this work has been documented (15,16). The success of the CCP for wastewater in Ontario led to an initiative to apply this approach to drinking water treatment facilities. The Ministry, in partnership with the Regional Municipality of Niagara, conducted CPEs at two plants in the Niagara Region.

1.3 SCOPE

A total of 23 CPEs and 3 CTAs conducted in the U.S. and Ontario provides the basis for the procedures presented in this handbook. It is noted that the handbook is an interim document and the methodology described may be refined based on regulatory changes and the experience gained from additional CPEs and CTAs conducted in Ontario over the next several years.

Figure 1-1 depicts the methodology for improving plant performance used in this handbook. As a first step, it is assumed that users of this handbook will be aware of the USEPA's SWTR and the Ontario Drinking Water Objectives (ODWO), and will have recognized a need to evaluate the capability of an existing water treatment facility to improve performance. Next, an evaluation approach (the CPE as described in Chapter 2) to estimate existing facility capability is implemented. If improved performance appears possible through optimization of existing facilities, then a systematic approach to address identified deficiencies (the CTA as described in Chapter 3) is implemented to achieve the improved performance. If this is not achieved, further detailed investigation may identify that either 1) capital expenditures must be made at the existing facility or 2) new facilities must be designed and constructed. The CCP approach and this Handbook emphasize modifying existing facilities to meet desired performance at existing water demands. If existing facilities are inadequate, another approach (e.g. a "process audit") must be utilized that includes activities that assess the need for increased capacity as well as improved performance.

FIGURE 1-1. Methodology for Achieving Plant Compliance



The intended users of this handbook are utilities, consultants, regulatory personnel and others associated with the responsibility of achieving compliance or more consistent performance from existing surface water treatment plants using conventional or direct filtration unit processes. Although the CCP approach is applicable to all sizes of systems, the MOE experience is that smaller systems are most in need of optimization. The performance improvement activities are directed at achieving improved particulate removal and adequate disinfection. There is limited emphasis on removal of naturally-occurring organics and control of disinfection byproducts. While this handbook deals with in-plant production of water, users should always be aware of the importance of maintaining treated water quality in the distribution system.

1.4 USING THE HANDBOOK

The text of the handbook parallels the two major steps of the CCP approach. Chapter 2 discusses an evaluation technique (the CPE) to identify causes for poor plant performance and to project the capability of existing facilities for achieving compliance. The CPE is also used to assess whether or not the next phase of performance improvement should be pursued. Chapter 3 describes methods of improving performance of existing facilities (the CTA) without major capital improvements. These methods are used to correct those design, operation, maintenance, and administrative factors identified in the CPE as limiting performance. If desired performance and/or compliance with applicable drinking water objectives is not achieved, the design factors that continue to limit performance are identified.

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2. COMPREHENSIVE PERFORMANCE EVALUATION

2.1 INTRODUCTION

This chapter provides information on the initial phase of a two-phase process to improve the performance of existing surface water treatment plants. This evaluation phase, called the Comprehensive Performance Evaluation, is a thorough review and analysis of a facility's design capabilities and associated administrative, operational, and maintenance practices as they relate to the performance requirements for the plant. A primary objective is to determine if significant improvements in treatment performance can be achieved without major capital expenditures.

2.2 CPE METHODOLOGY

A CPE is a comprehensive evaluation of the administration, design, operation and maintenance of a surface water treatment facility. Although the evaluation focuses on the current condition of the facility (i.e., a "snapshot in time"), consideration is given to seasonal variations in raw water quality. A CPE involves several activities: evaluation of the major unit processes, assessment of plant performance, identification and prioritization of performance limiting factors, assessment of applicability of follow-up CTA, and reporting results of the evaluation. Although these are distinct activities, some are conducted concurrently with others. For example, evaluation of major unit processes and identification of performance-limiting factors are generally conducted simultaneously. A discussion of these activities follows.

2.2.1 Evaluation of Major Unit Processes

2.2.1.1 Overview

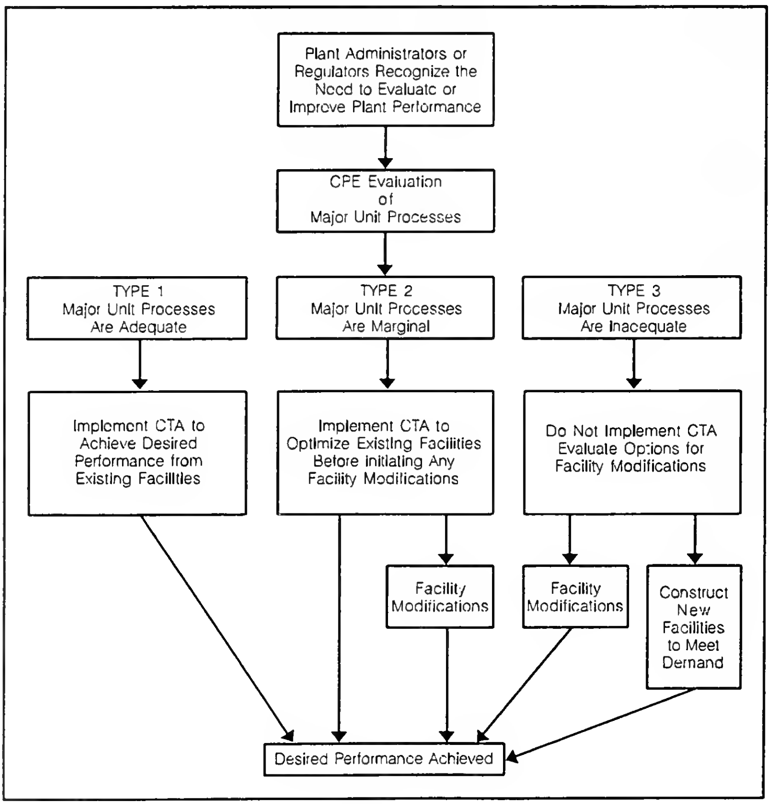
The major unit process evaluation is used to establish the <u>potential</u> of existing processes to achieve desired performance levels. If the CPE indicates that the major unit processes are adequate, a major plant upgrade or expansion is probably not necessary, and a properly conducted CTA should be implemented to optimize performance. If, on the other hand, the CPE shows that major unit processes are inadequate, utilities should consider modification of these processes as the initial focus for achieving desired performance.

A rating system is used that allows the evaluator to rate each unit process and the overall plant as either Type 1, 2 or 3. This evaluation approach is illustrated in Figure 2-1. Type 1 plants are those where a CPE shows that current performance difficulties are not caused by limitations in the size or capability of existing unit processes. In these cases, problems are likely related to plant operation, maintenance, or administration. Type 1 plants are projected to be most likely to achieve desired performance through implementation of nonconstruction-oriented follow-up assistance (e.g., a CTA as described in Chapter 3).

The Type 2 category is used to represent a situation where marginal capacity of unit processes could potentially prohibit a plant from achieving the desired performance level. For Type 2 facilities, it is projected that implementation of a CTA would lead to improved performance, but might not achieve the required performance level without facility modifications to the major treatment units.

Type 3 plants are those in which major unit processes are projected to be inadequate to provide required capacity for existing water demands. For Type 3 facilities, major modifications are felt to be required to achieve the desired level of performance. Although other performance-limiting factors may exist, such as the operator's lack of process control capability or the administration's unfamiliarity with plant needs, consistent acceptable performance cannot be expected to be achieved until physical limitations of major unit processes are eliminated. If severe public health problems exist with present plant performance, officials may conduct activities to improve plant performance as much as possible until major modifications can be completed. A Boil Water Advisory (which can only be issued by the Medical Officer of Health) or water use restrictions may have to be implemented until modifications are completed and performance is improved. The owners of a Type 3 plant could meet their performance requirements by pursuing modifications of existing water treatment facilities. However, depending on future water demands, more detailed study of treatment alternatives may be warranted. CPEs that identify Type 3 facilities are still of benefit to plant administrators in that the need for construction is clearly defined. Additionally, the CPE provides an understanding of the capabilities and weaknesses of existing operation and maintenance practices and administrative policies.

Figure 2-1. Major Unit Process Evaluation Approach



2.2.1.2 Approach

Major unit processes are evaluated based on their capability to handle current peak instantaneous flow requirements. The major unit processes included in the evaluation are flocculation, sedimentation, filtration and disinfection. These processes are selected for evaluation based on the concept of determining if the "concrete" (e.g., basin size) is adequate. The potential capacity of a major unit process is not increased if "minor modifications", such as providing chemical feeders or installing baffles, could be accomplished by the staff. This approach is in line with the CPE intent of assessing adequacy of existing facilities to determine the potential of non-construction alternatives. Other components of the plant processes, such as rapid mix facilities, are not included in the major unit process evaluation but rather are evaluated separately as factors that may be limiting performance. These components can most often be addressed through "minor modifications".

An approach, using a "performance potential graph", has been developed to evaluate the major unit processes. As an initial step in the performance potential graph approach, the CPE evaluators are required to use their judgment to estimate the peak treatment capacity for each of the major unit processes. It is important to note that the ratings are based on achieving optimum performance from flocculation, sedimentation, filtration and disinfection such that each process maintains its integrity as a "barrier" to the passage of turbidity and/or cysts. This allows the total plant to provide a "multiple barrier" to the passage of pathogenic organisms into the distribution system. The projected treatment capacity rating is then compared to the peak instantaneous operating flow rate experienced by the water treatment plant during the most recent twelve months of operation. If the most recent twelve months is not indicative of typical plant flow rates, the evaluator may choose to review a time period considered to be more representative. The peak instantaneous operating flow is utilized for the comparison because it is necessary that high quality finished water be produced on a continuous basis.

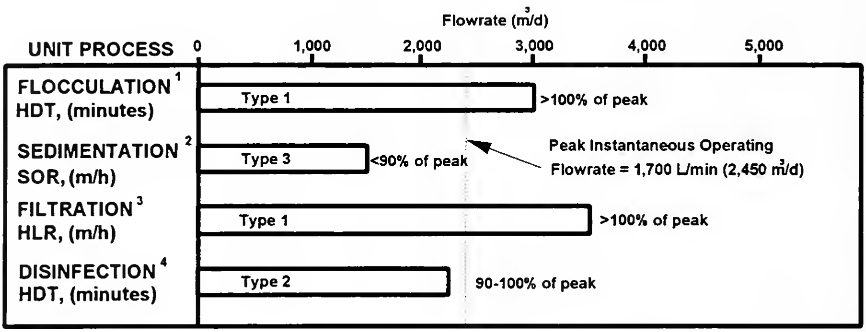
The comparison of estimated unit process treatment capacity to peak instantaneous operating flow rate is made using a performance potential graph, as shown in Figure 2-2. The processes evaluated are shown on the left of the graph and the flow rate units are shown on the "x" scale across the top. Horizontal bars on the graph depict the estimated capacity for each unit process, and the vertical dashed line represents the actual peak operating flow experienced at the plant. Footnotes are used to explain the conditions used to rate the unit processes.

The approach to determine whether a unit process is Type 1, Type 2 or Type 3 is based on the relationship of the horizontal bars to the peak instantaneous operating flow rate. As presented in Figure 2-2, a unit process would be rated Type 1 if its projected capacity exceeds the actual peak demand, Type 2 if its projected capacity was 90 to 100 percent of actual peak demand, or Type 3 if its projected capacity is less than 90 percent of actual peak demand.

When rating the capability of a unit process, it is important to consider several options that are available for water treatment facilities. For example, if a unit process receives a Type 3 rating, it may be able to achieve Type 2 or Type 1 status by reducing demand or by extending the operating time and operating at a lower rate (e.g., if the peak instantaneous operating flow rate of a plant is only occurring over a 12-hour period, the plant may be able to be operated at half the flow rate for a 24-hour period). In addition, it may be possible for a community to take steps to reduce demand by activities such as increasing water rates, water rationing, or leak detection and repair. In these instances, the potential to decrease peak instantaneous operating flow rate needs to be carefully assessed by the evaluator in order to justify a

change in the unit process rating (see Section 2.2.2.3).

FIGURE 2-2. Example Performance Potential Graph.



Comments:

1. **Rated at 20 minutes hydraulic detention time (HDT)**
2. **Rated at 1.25 m/h surface overflow rate (SOR) - 3.5 m depth discourages higher rating.**
3. **Rated at 12 m/h hydraulic loading rate (HLR) - dual media.**
4. **Based on 4.0 log total log reduction, 2.5 log by removal, 1.5 log by disinfection; conditions are pH = 8, temp. = 5C, and max. acceptable free residual = 2.4 mg/L; CT required = 127 mg-min/L which requires 53-min. HDT for chlorine contact. Assumes 10% of clearwell volume is effectively used for chlorine contact due to unbaffled condition.**

2.2.1.3 Rating Individual Unit Processes

The criteria presented in Table 2-1 are used as a basis to rate individual unit processes. There is a wide range in the criteria which can translate into large differences in estimated unit process capabilities. As such, using the performance potential graph approach requires a great deal of judgment on behalf of an experienced water treatment evaluator to properly estimate the capacity of a major unit process. These criteria are based on experience gained from CPEs and other sources including the MOE Design Guidelines (1,2,3,4,5).

Major unit process performance is assessed, both with respect to the capability of consistently contributing to overall plant treated water quality and with respect to providing consistent individual unit process performance. Unit process performance capability is important to ensure that multiple barriers are maintained on a continuous basis. Specific performance requirements by which each major unit process is assessed are described in the following sections.

TABLE 2-1. Criteria for Major Unit Process Evaluation Using the Performance Potential Graph Rating System

UNIT PROCESS		
FLOCCULATION		
Hydraulic Detention Time (HDT), minutes	15 - 40	
Velocity Gradient (G), sec $^{-1}$	10 - 75	
Stages	2 - 3	
SEDIMENTATION		
Surface Overflow Rate (SOR), m/h (Igpm/ft^2)		
Conventional Rectangular Horizontal Flow	1.25 - 2.50	(0.4 - 0.8)
Above with Tube Settlers*	2.5 - 5.0	(0.8 - 1.7)
Upflow Solids Contact Type Clarifiers	2.0 - 3.0	(0.7 - 1.0)
Above with Tube Settlers*	4.0 - 6.0	(1.4 - 2.0)
Depth, m (ft)	3 - 5	(11 - 16)
FILTRATION		
Filter Rate, m//h (Igpm/ft^2)		
Mono Media	2 - 7	(0.7 - 2.4)
Dual/Mixed Media	7 - 18	(2.4 - 6.1)
Backwash Rate, m^3/m^2/h (Igpm/ft^2)	42 - 54	(14 - 18)
Bed Expansion During Backwash, %	25 - 40	
Backwash Duration, minutes	10 - 15	
DISINFECTION (See Section 2.2.1.3.4)		

* Based on the area of the tube settler module.

Flocculation

The projection of flocculation basin capacity is based primarily on available hydraulic detention time (HDT). Required detention time for adequate flocculation is highly variable depending on water temperature and downstream processes. In summer HDTs of 25-30 minutes are usually sufficient. However, when water

temperatures are less than 5 °C, floc formation can be delayed. In these instances, longer (30 - 40 minute) detention times may be assessed as being required. The evaluator must remember that plant flows are generally lower in winter, but not always. In northern Ontario, flows are often highest during winters when consumers allow their taps to run constantly to avoid frozen service lines. Consideration must also be given to whether or not the plant is or could be operated in a direct filtration mode. In this case detention times as low as 15 minutes could be assessed to be adequate. Because of these variables, evaluators must use judgement when rating the required hydraulic detention time of flocculation basins.

Consideration is also given to the number of flocculation stages, with at least two considered desirable. The availability of variable energy input to control mixing intensity (i.e. G values) is also considered. However, since variable mixing energy and staging can often be added as "minor" modifications, these items are not considered as significant in the capacity rating. If adequate basin volume is available (e.g. typically a Type 1 unit process), a one-stage flocculation basin may result in a Type 2 capability rating and follow-up CTA activities would be required to establish if added baffling or flocculator drives could improve performance.

Sedimentation

The projection of sedimentation basin capacity is primarily based on surface overflow rate (SOR) with consideration given for depth and sludge removal characteristics. In general, shallow basins (e.g., less than 3.5 m) would receive a rated capacity based on the lower SORs shown in Table 2-1. In cases where flocculated colour (a lightweight floc) and/or low temperatures are encountered, rated capacity will likely be based on the lower SORs in Table 2-1. Criteria are shown for rectangular and upflow solids contact units with or without tube settlers.

Sedimentation basin performance is assessed based on achieving a maximum settled water turbidity of 2 NTU on a continuous basis for all raw water qualities. This assures the sedimentation process as a viable barrier in the treatment scheme.

Filtration

Projection of filtration capacity is based primarily on hydraulic loading rates, with consideration given to media type. For example, a mono-media sand filter may be assessed at a maximum rate of 7 $m^3/m^2/h$ because of the tendency of this filter to surface blind by removing particles at the top of the filter media; whereas a dual or mixed media filter may be assessed at a 7 to 18 m/h rate because of the ability to utilize the solids storage capacity within the anthracite layer.

Limitations in media depth and backwash facilities also impact the selected loading rate for estimating a filter's capacity. Limitations in these areas will bias the rating toward more conservative values within each range. It is noted that deficiencies in these areas can often be addressed through minor modifications and therefore are assessed to have less impact than hydraulic loading rate.

Filter performance should be assessed based on the capability to achieve effluent turbidity of less than 0.1 NTU continuously to ensure the integrity of filtration as a viable barrier in the treatment scheme. This is less than the 1.0 NTU Ontario Drinking Water Objective, but operation of filters to produce filtered water quality of less than 0.1 NTU is attainable by many plants, and provides greater confidence that pathogens such as *cryptosporidium* and *giardia* are being removed prior to the final barrier, disinfection.

Disinfection

The existing MOE policy regarding disinfection is based on the MOE Chlorination Bulletin (6), most recently updated in 1987. The bulletin calls for *"a total chlorine residual of at least 0.5 mg/L after a minimum of 15 minutes of contact after filtration and before the first consumer. It is preferable that most of the chlorine residual is in the form of free chlorine. In cases where surface water treatment plants are able to consistently achieve filtered turbidities of 1.0 NTU or less together with a contact time of at least 2 hours, a minimum total chlorine residual of 0.2 mg/L is allowable."* It should be noted that since 1997 the MOE Approvals Branch has gone further and now issues certificates of approval that stipulate a free chlorine residual of 0.5 mg/L and a contact time of 60 minutes for plants treating surface water.

The existing MOE policy is under review and may be revised to take into account disinfectants other than chlorine, the varying resistance to disinfection of the various target pathogenic organisms, the considerable effect that pH and temperature have on the effectiveness of the various disinfectants, and short-circuiting in process tankage. Assessment of disinfection as per the USEPA's Surface Water Treatment Rule (SWTR) (7) takes the above factors into account, and a similar approach will probably be incorporated into a future revised MOE disinfection policy. For these reasons, this MOE handbook will present a scheme for assessing disinfection based on the USEPA's SWTR. The SWTR requires a minimum of 99.9 percent (3-log) inactivation and/or removal of *Giardia lamblia* cysts and at least 99.99 percent (4-log) inactivation and/or removal of viruses.

The USEPA has published a guidance manual (8) that presents an approach to assure that required levels of disinfection are achieved. The approach uses the concept of assessing the product of the concentration of the disinfectant "C" and the time "T" that the finished water is in contact with the disinfectant. CT values are provided in the guidance manual that will provide various log inactivations for different temperatures, pH, and disinfectant residuals. Cyst and virus log removal credits for the different types of physical treatment processes are also provided in the guidance manual. The guidance manual also indicates that, while the 3-log and 4-log inactivation/removals are the minimum required, the number of log inactivation/removals may need to be increased if the raw water source is subjected to excessive contamination from cysts and/or viruses.

The following are procedures for assessing the capability of a plant to meet the disinfection requirements based on the CT values in the USEPA guidance manual. Procedures are presented for both pre- and post-disinfection with pre-disinfection defined as adding the disinfectant ahead of the filters and post-disinfection as adding the disinfectant after the filters. Both procedures are presented, not to endorse the use of pre-chlorination, but to acknowledge that in some cases the practice may be necessary to achieve the required level of disinfection.

Post-Disinfection:

- Estimate the log reduction required by water treatment processes based on the raw water quality or watershed characteristics. Under the SWTR, the standard requirement for a watershed of reasonable quality is a 3-log reduction of *Giardia* cysts or 4-log reduction of viruses. More reduction may be required for an unprotected watershed exposed to factors such as wastewater treatment effluents.

- Estimate the log removal capability of the existing treatment plant. Judgment is required to project the ability of existing processes to perform at the peak instantaneous operating flow rate. Expected removals by various types of filtration plants are presented in Table 2-2. As shown, a 2.5-log *giardia* removal may be allowed for a conventional plant with adequate unit treatment process capability (e.g. Type 1 units).

TABLE 2-2. Expected Removals of *Giardia* Cysts and Viruses by Filtration[8]

Expected Log Removals		
Filtration	*Giardia*	Viruses
Conventional	2.5	2.0
Direct	2.0	1.0
Slow Sand	2.0	2.0
Diatomaceous Earth	2.0	1.0

- Select a required CT value based on the required log inactivation (i.e. required log reduction minus the log removal capability of the plant), the maximum pH and minimum temperature of the water being treated, and the projected maximum chlorine residual that could be used in the system. The projected chlorine residual is based on the chlorine dose considering disinfection system feed capability and the maximum residuals tolerated by the consumer. The maximum chlorine residual utilized in any evaluation should be 2.5 mg/L free residual, based on research which indicates that contact time is more important than disinfectant concentration at free chlorine residuals above 2.5 mg/L (9). CT values for inactivation of *Giardia* cysts and viruses are presented in Appendix A.

- Select an effective volume of the existing clearwell and/or distribution pipelines to the first user. Effective volume refers to the volume of basin or pipeline that is available to provide adequate contact time for the disinfectant. Adequate time is referred to in the SWTR as T_{10}, which is the time it takes 10 percent of a dye or tracer to be detected at the basin outlet after it is injected into the basin influent flow. If a tracer study has been conducted, the results should be utilized in determining the effective contact time. If tracer studies have not been conducted, the effective volume upon which contact time will be determined can be calculated by multiplying the nominal hydraulic detention time by a factor. For example, an unbaffled clearwell may have an effective volume of only 10 percent (factor = 0.1) of actual basin volume because of the potential for short circuiting; whereas, a transmission line could be based on 100 percent (factor = 1.0) of the line volume to the first tap because of the plug flow characteristics. A summary of factors to determine effective volume versus actual volume based on baffling characteristics is presented in Table 2-3. Caution is urged when using a factor from Table 2-3 of greater than 0.1 to estimate additional disinfection capability for unbaffled basins. The limited amount of tracer test information available indicates that actual contact times in typical full-scale clearwells are close to 10 percent of theoretical. Increasing this factor for basins where special baffles have not been installed is not recommended unless tracer test information is available.

- Using these parameters, calculate a detention time (i.e. CT value required for inactivation divided by projected chlorine residual). Compare this value to the available detention time (i.e. effective volume divided by peak instantaneous operating flowrate) to assess the performance capability of the post disinfection process. Example calculations are presented in Section 2.3.5.

Pre-Disinfection:

The following procedure has been developed for pre-disinfection based on the requirements in the SWTR guidance manual published by the USEPA. The procedure has only been used to determine the additional disinfection capability provided if pre-disinfection is actually being practiced at the utility being evaluated. When pre-disinfection is practiced, the performance potential graph should be developed with two bars for disinfection: one including pre-disinfection and one without. This allows the plant owners to assess disinfection capability if pre-disinfection was excluded (e.g. if disinfection byproducts became a limitation on the process given the revised THM objective in Ontario).

- Estimate the log reduction required by water treatment processes based on the raw water quality or watershed characteristics as presented in the post-disinfection procedure.

- Estimate the log removal capability of the existing treatment plant as presented in the post-disinfection procedure. Expected removals by various types of filtration plants are presented in Table 2-2.

TABLE 2-3. Factors to Evaluate Effective Disinfection Contact Time Based on Actual Basin Characteristics(7)

Baffling Condition	Factor	Baffling Description
Unbaffled	0.1	None; agitated basin, high inlet and outlet flow velocities, variable water level.
Poor	0.3	Single or multiple unbaffled inlets and outlets, no intra-basin baffles.
Average	0.5	Baffled inlet or outlet with some intra-basin baffling.
Superior	0.7	Perforated inlet baffle, serpentine or perforated intra-basin baffles, outlet weir or perforated weir.
Excellent	0.9	Serpentine baffling throughout basin.
Perfect (plug flow)	1.0	Pipeline flow.

- Select a required CT value for both pre- and post-disinfection from the tables in the SWTR guidance document based on the required log inactivation (i.e. required log reduction minus the log removal capability of the plant), the maximum pH and minimum temperature of the water being treated, and the projected maximum chlorine residual. The required CT values may be different for the pre- and post-disinfection conditions if different temperatures, pH, and chlorine residuals exist for both conditions. For example, addition of lime or soda ash to increase the pH of finished water would change the required CT value for post-disinfection relative to pre-disinfection.

The projected chlorine residuals are selected for pre- and post-disinfection based on the chlorine dose considering disinfection system feed capability and maximum residuals considered practical. As discussed in the post-disinfection procedure, a 2.5 mg/L free chlorine residual is considered a maximum for post-disinfection. A 1.5 mg/L free chlorine residual is used as the maximum for pre-disinfection unless actual plant records support selection of a higher residual. CT values for inactivation of *Giardia* cysts and viruses are presented in Appendix A.

- Select an effective volume available to provide adequate contact time for both pre- and post-disinfection. For post-disinfection, use the same effective volume used when assessing the capabilities of post-disinfection alone. For pre-disinfection, assess which basins and lines will provide contact time. These are typically the flocculation and sedimentation basins, but could include raw water transmission lines if facilities exist to inject chlorine prior to the plant. Filters are normally not included because of the short detention times typically inherent in the filters and the reduction in chlorine residual that often occurs through filters. The actual basin volumes should be converted to effective volumes by applying factors described in Table 2-3 and discussed previously in the post-disinfection procedure.

- Calculate a flow rate where the plant will achieve the required CT values for both pre- and post-disinfection using the formula below. Use this flow rate to establish the pre- and post-disinfection system capability on the performance potential graph.

$$Q = \left[\frac{C_{pre} \times V_{pre}}{CT_{reqpre}} \right] + \left[\frac{C_{post} \times V_{post}}{CT_{reqpost}} \right]$$

Where:

Q = Flow rate where required CT is met.

CT_{req} = CT requirements from Tables in Appendix A for pre- and post-disinfection conditions.

V_{pre} = Effective volume for pre-disinfection system.

V_{post} = Effective volume for post-disinfection system.

C_{pre} = Free chlorine residual used for pre-disinfection system.

C_{post} = Free chlorine residual used for post-disinfection system.

2.2.2 Conducting Performance Assessment

The performance assessment step uses existing and on-site data evaluations to determine if unit process and total plant performance have already been optimized. Performance of each unit process, flocculation, sedimentation, filtration and disinfection are assessed to ensure that multiple barriers are in place such that continuous optimum performance is achieved. This includes assessment of the presence of short periodic breakdowns in treatment caused, for example, by "bumping a filter" which releases previously trapped particles. Such a practice could have a significant health effect if the particles are *Giardia* or *Cryptosporidium* cysts and therefore represents a poorly performing facility. Using this criteria, it is possible to identify poorly performing unit processes and thus poorly performing plants even though these facilities may have reported compliance with turbidity objectives.

2.2.2.1 Plant Operating Records

During the evaluation of plant data, laboratory quality control (especially calibration of turbidimeters) and sample locations should be reviewed to ensure that proper sampling and analysis have provided data that is truly representative of plant performance. Review and evaluation of acceptable plant operating records for the most recent twelve months or other representative period can then be pursued. Data should be collected and evaluated for raw water, settled water, and finished water, and for individual filter effluent, if available. The use of a computer spreadsheet to tabulate and graph the turbidity data versus time and to conduct a frequency analysis of the data can assist in evaluating performance. A good indication of the stability of plant operation can often be obtained from comparing a plot of raw water, settled water and finished water turbidity for the twelve-month evaluation period. When comparing these data, the evaluator should look for consistent settled and filtered water turbidities even though raw water quality may vary significantly. Acceptable performance for filters and sedimentation basins should be assessed based on achieving filtered water and settled water turbidities consistently less than 0.1 NTU and 2 NTU respectively, even though raw water quality may fluctuate widely.

A frequency analysis allows the evaluator to determine the percent of time that raw, settled or finished water quality achieves a certain turbidity. This can be used to assess the variability of raw water turbidity and the performance of sedimentation and filtration unit processes. Frequency plots of finished water quality with 12 months of data are useful tools for projecting a plant's compliance capability. The twelve month analysis is also desirable because it includes on a single graph the impacts of seasonal variations and provides a good indicator of long term performance.

A typical plant filtered water turbidity plot is shown in Figure 2-3. The variability of finished water turbidity shown in this plot is unacceptable and indicative that plant performance has not been optimized. The frequency plot of these same data (Figure 2-4) projects that the plant, as presently operated, would achieve a 1.0 NTU level at the 85th percentile i.e. 15 percent of the samples were above the 1.0 NTU level.

Despite the usefulness of existing data, the experience of MOE and others is that operating records often do not represent actual performance because of improper turbidimeter calibration and the location and timing of sample collection. An example of non-representative sampling is collecting turbidity samples from the clearwell only once each day. This sample can be further biased by collecting the sample immediately after the plant has been placed in operation. Samples collected in this fashion have not been found to be representative of actual performance. As a minimum, the Ontario Drinking Water Objectives

(ODWO) requires turbidity sampling of plant finished water every four hours; however, CPE results have indicated that even this may not be frequent enough to identify significant short term excursions from acceptable performance. Continuous monitoring and recording of turbidity from each filter allows the identification and correction of short term turbidity excursions.

FIGURE 2-3. Example Finished Water Turbidity Profile

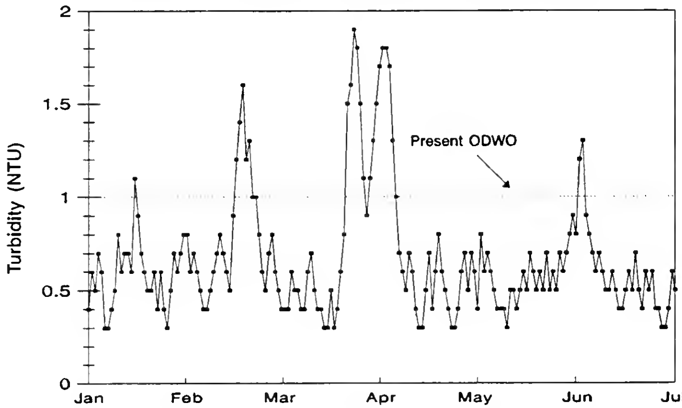
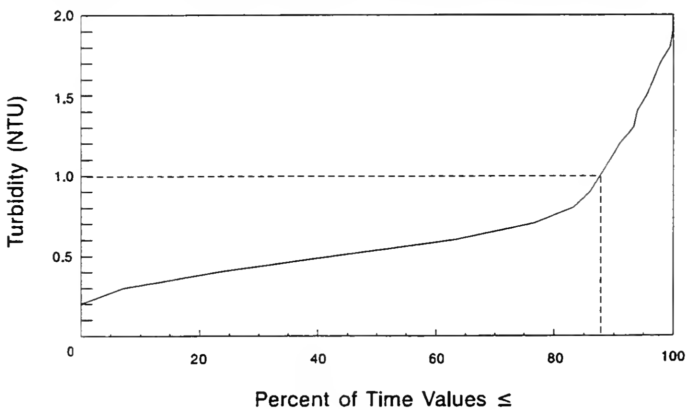


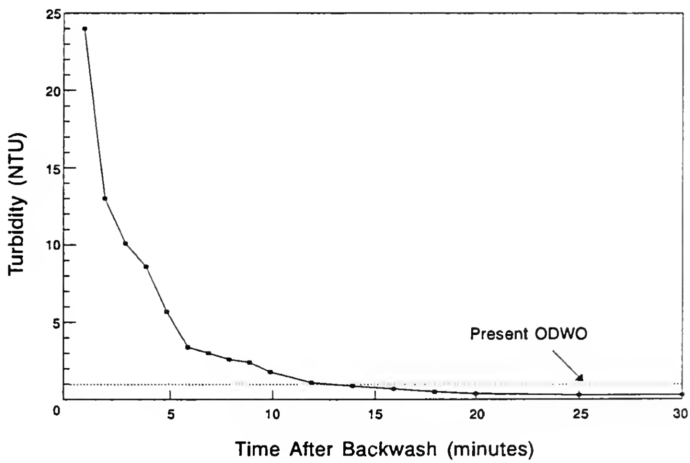
FIGURE 2-4. Example Percentile Plot of Finished Water Turbidity



2.2.2.2 Special Study Data

To supplement existing plant data, special studies should be performed during a CPE. A typical special study is a time versus turbidity profile conducted on filters before and after backwashing. Acceptable performance is judged to be an increase in filtered water turbidity of less than 0.2 to 0.3 NTU for less than 10 minutes following a backwash. An example of unacceptable filter performance is depicted in the turbidity versus time graph presented in Figure 2-5. As shown, a significant breakthrough of turbidity occurred after the backwash (e.g., turbidity increased to 24 NTU). Samples taken from the clearwell at the same time showed turbidity values of 6.3 NTU, far in excess of current or proposed regulatory criteria. Other special studies include developing a turbidity profile after starting a dirty filter, profiling turbidities from the sedimentation basins, and continuous monitoring of turbidities from individual filters and the clear well.

FIGURE 2-5. Filter Effluent Turbidity vs. Time



The use of a continuous recording turbidimeter in the conduct of special studies provides more accurate results and often reveals performance problems that may not be noticed through conventional grab sampling. In a plant that has multiple filters it is advantageous to collect grab samples from individual filters for turbidity analysis before selecting the filter that is to be monitored by the continuous recording turbidimeter. The poorest-performing filter should be selected.

2.2.2.3 Assessment of Plant Operating Capacity

Another important aspect of the performance assessment is a determination of peak instantaneous operating flow rate. Accurate assessment of instantaneous peak operating flow rate is important for two reasons. First, this is the flow rate against which the capability of each of the major unit processes is assessed

during conduct of the major unit process evaluation using the performance potential graph. Based on this assessment, the unit process type (1, 2 or 3) is projected, which determines if major construction could be required at the plant. Second, evaluation of the peak instantaneous operating flow rate and plant operating time allows the evaluator to determine if plant performance can be improved by reducing the plant flow rate and extending the plant operating time. It is noted that at many plants evaluated to date in the U.S. this capability has existed, allowing a plant to be projected as capable of being brought into compliance with SWTR requirements without major facility improvements. Many smaller plants in Ontario are also operated for only a fraction of the day, and this capability exists here as well.

Peak instantaneous operating flow rate has to be identified through review of operating records and observation of operation practices and flow control capability. Flow records can be reviewed to determine the peak daily water demand. Through discussions with the operating staff it can be determined whether the peak demand occurred when the plant was operated for a full 24-hour period. If the peak demand was for a full 24-hour period then the calculated flow rate equals the peak instantaneous operating flow. If the plant does not operate at 24 hours/day, peak instantaneous operating flow is actually the peak flow rate at which the plant is operated. For example, a plant may have two constant speed raw water pumps each rated at 63 L/s. If only one is operated at a time, the peak instantaneous flow rate would be established at 63 L/s. If operating personnel indicate that a control valve is used to throttle plant flow to 47 L/s on a continuous basis, the peak instantaneous flow rate would be established at 47 L/s.

2.2.3 Identification and Prioritization of Performance Limiting Factors

2.2.3.1 Identification of Performance Limiting Factors

A significant aspect of any CPE is the identification of factors that limit the existing facility's performance. This step is critical in defining the focus of follow-up efforts. To assist in factor identification, a list of 65 different factors that could potentially limit water treatment plant performance is provided in Appendix B. These factors are divided into broad categories of administration, maintenance, design and operation. Definitions of each factor are provided. This list and definitions have been updated and modified based on the results of the 21 water treatment plant CPEs that have been conducted in the U.S. (plus two others in Ontario), and is provided for convenience and reference. If alternate names or definitions provide a clearer understanding to those conducting the CPE, they can be used. However, if different terms are used, each factor should be defined and these definitions should be readily available to those conducting the CPE and interpreting the results. It is desirable, however, to adopt a consistent list to allow comparison from plant to plant. Note that the list includes factors on capacity of major unit processes. If the evaluation of major unit processes results in a Type 2 or 3 classification, these results can then be documented in the overall list of factors identified as limiting an existing plant's performance.

A factor should only be identified if it impacts plant performance. As such, an observation that a factor does not meet a particular "industry standard" (e.g., a documented preventive maintenance program or good housekeeping practices) does not necessarily indicate a performance limiting problem. An actual link between poor plant performance and the identified factor must exist. Properly identifying a plant's unique list of factors is difficult because the actual problems in a plant are often masked. This concept is illustrated in the following discussion.

A review of plant records revealed that a conventional water treatment plant was periodically producing finished water with a turbidity of about 1.2 NTU. The utility, assuming that the plant was operating beyond its capability, was beginning to make plans to expand both the sedimentation and filtration facilities of the plant. Special studies conducted as part of a CPE revealed that settled water and finished water turbidities averaged about 15 NTU and 3.5 NTU, respectively. Filtered water turbidities peaked at 25 NTU for short periods following a filter backwash. Initial observations could lead to the conclusion that the plant's sedimentation and filtration facilities were inadequately sized. However, further investigation revealed the poor performance was caused by the operator adding coagulants at dosages 200 percent higher than required, leading to formation of a pin floc that would not settle or filter, and operating the plant at its peak capacity for only 8 hours each day, resulting in the washout of solids from the sedimentation basins. It was determined that implementing proper process control of the plant and operating the plant at a lower flow rate for 16 hours each day would allow the plant to continuously achieve acceptable finished water quality. It was further determined that the reason the plant was not operated for longer periods of time was an administrative policy that limited plant staff to one person, which made both 16-hour and weekend coverage difficult. Staffing with one operator would not allow continuous successful operation of the plant because there would be periods of time when necessary process control adjustments could not be made.

It was concluded that four factors contributed to the poor performance of the plant:

1. Operator Application of Concepts and Testing to Process Control - Inadequate operator knowledge to determine proper coagulant doses and to set chemical feed pumps to apply the correct chemical dose.

2. Administrative Policies - Restrictive administrative policy that prohibited hiring an additional operator to allow reduced plant operating flow rate by increasing operating time.

3. Process Control Testing - Inadequate test equipment and sampling program to provide process control information.

4. Administrative Familiarity With Plant Needs - Poor administrative guidance that resulted in a rate structure that would not support the needs of the plant.

Given the above observations, plant expansion was not required.

The above discussion illustrates that a comprehensive analysis of a performance problem is essential to identify the actual performance limiting factors. If the initial conclusions regarding sedimentation and filtration capacity had been pursued, improper corrective actions in the form of unnecessary expenditures would probably have occurred. Instead, addressing the operational and administrative factors identified would allow the plant to produce an acceptable finished water on a continuous basis without major expenditures for construction.

2.2.3.2 Prioritization of Performance Limiting Factors

After all performance limiting factors are identified they are prioritized in order of their adverse effect on allowing desired plant performance to be achieved. This prioritization establishes the sequence and/or emphasis of follow-up activities necessary to optimize facility performance. For example, if the highest ranking factors (i.e., those having the most negative impact on performance) are related to physical limitations in unit process capacity, initial corrective actions are directed toward defining plant modifications and obtaining administrative funding for their implementation. If the highest ranking factors are process control-oriented, initial emphasis of follow-up activities would be directed toward plant-specific operator training.

Prioritization of factors is accomplished by a two-step process. First, all factors that have been identified are individually assessed with regard to adverse impact on plant performance and assigned an "A", "B" or "C" rating (Table 2-4). The checklist of factors in Appendix B includes a column to enter this rating. The second step of prioritizing factors is to list those receiving "A" rating in order of severity, followed by listing those receiving "B" rating in order of severity. "C" factors are not prioritized.

TABLE 2-4. Classification System for Prioritizing Performance Limiting Factors

Rating	
A	Major effect on long-term repetitive basis.
B	Minimum effect on routine basis or major effect on a periodic basis.
C	Minor effect.

"A" factors are major sources of a performance deficiency and are the central focus of any subsequent improvement program. An example "A" factor would be sedimentation facilities that are inadequate to reduce the turbidity loading to the filters at all times of the year, such that desired finished water quality cannot be achieved.

Factors are assigned a "B" rating if they fall in one of two categories:

- Those that routinely contribute to poor plant performance but are not the major problem. An example would be insufficient plant process control testing where the primary problem is that the staff does not understand coagulation chemistry, how to run or interpret jar tests, or understand the need for additional process control testing.

- Those that cause a major degradation of plant performance, but only on a periodic basis. A typical example are sedimentation basins that cause periodic serious problems during spring run-off.

Factors receive a "C" rating if they contribute to a performance problem, but have minor effect. For example, if raw water was being sampled from the rapid mix after chemical feed, it could indirectly contribute to poor performance since raw water testing would not be representative of actual conditions. The problem could be easily corrected and would not be a major focus during follow-up correction activities.

As a comparison of the different ratings, the example "A" factor above (sedimentation) would receive a "B" rating if the basin was only inadequate periodically, for example, during a run-off event. The factor would receive a "C" rating if the basin size and volume were adequate, but minor baffling was required to improve its performance. Typically, 5 to 15 factors are identified during a CPE. The remaining 50 to 60 factors that are not identified as performance limiting represent a significant finding. For example, in the example presented in Section 2.2.3.1, neither sedimentation or filtration was identified as a performance limiting factor. Since they were not identified, plant personnel need not focus on the sedimentation basins or filters as a problem, which would preclude spending large amounts of capital to upgrade these facilities. Factors that are not identified are also a source for providing recognition to plant personnel for adequately addressing these potential sources of problems.

Once each identified factor is assigned an "A", "B", or "C" classification, those receiving "A" or "B" ratings are listed on a one page summary sheet (see Appendix B) in order of assessed severity on plant performance. The prioritized summary list of factors provides a valuable reference for the next step of the CPE, assessing the ability to improve performance, and serves as the foundation for implementing correction activities if they are deemed appropriate.

All factors limiting facility performance typically may not be identified during the CPE phase. It is often necessary to later modify the original corrective steps as new and additional information becomes available during conduct of the performance improvement (CTA) phase.

2.2.3.3 Evaluation of Performance Limiting Factors

Evaluation of administration, maintenance, design and operation factors occurs throughout the conduct of a CPE. Following are some useful observations in identifying factors in these areas.

<u>Administration Factors</u>

The evaluation of administrative performance limiting factors is a subjective effort, primarily based on management and staff interviews. In small plants the entire staff, budgetary personnel, and plant administrators, including one or two elected officials, should be interviewed. These interviews are more effective after the evaluator has been on a plant tour and has completed enough of the data development activities (including the major unit process and performance assessment evaluations) to become familiar with plant capabilities and past performance. With this information, the evaluator is better equipped to ask insightful questions about the existing plant. To accurately identify administrative factors requires aggressive but non-threatening interview skills. The evaluator must always be aware of this delicate balance when pursuing the identification of administrative factors.

Budgeting and financial planning are the mechanisms that plant owners/administrators generally use to implement their objectives. Therefore, evaluation of these aspects is an integral part of efforts to identify the presence of administrative performance limiting factors. Smaller utilities often have financial

information combined with other utilities, such as wastewater treatment, street repairs, and parks and recreation. Additionally, nearly every utility's financial information is set up differently. Therefore, it is necessary to review information with the assistance of plant and/or budgetary personnel to rearrange the line items into categories understood by the evaluator. Forms for comprehensively collecting plant information, including financial information, have been developed and are presented in Appendix C. These forms allow a consistency in development of financial information.

When reviewing financial information, it is important to determine whether the rate structure creates sufficient revenue to adequately support the plant. Water system revenues should provide an adequate number of fairly paid staff and exceed expenditures enough to allow establishment of a reserve fund for future plant modifications.

Typically, all administrators verbally support goals of low costs, safe working conditions, good plant performance, and high employee morale. An important question that the evaluator must ask is, "Where does treated water quality fit in?". Often, administrators are more concerned with water quantity than quality, and this question can be answered by observing the items implemented or supported by the administrators. If a $12 million dollar reservoir project is being implemented while the plant remains unattended and neglected, priorities regarding quality and quantity can be easily discerned.

An ideal situation is one in which the administrators function with the awareness that they want to achieve high quality finished water as the end product of their water treatment efforts. Improving working conditions, providing adequate numbers of qualified staff, lowering treatment costs and other similar goals would be pursued within the realm of first achieving high quality finished water.
At the other end of the spectrum is an administrative attitude that "We just raised rates 25 percent last year and we can't afford to spend another dime on that plant; besides my family used to drink untreated water from the river and no one got sick." Administrators who fall into this category, typically are identified as contributing to inadequate performance during factor identification activities.

Technical problems identified by the plant staff or the CPE evaluator, and the potential costs associated with these problems, often serve as the basis for assessing administrative factors limiting performance. For example, the plant staff may have correctly identified needed minor modifications for the facility and presented these needs to the utility manager, but had their requests declined. The evaluator must solicit the other side of the story from the administrators, to see if the administration is indeed non-supportive in correcting the problem. There have been numerous instances in which operators or plant superintendents have convinced administrators to spend money to "correct" problems that resulted in no improvement in plant performance.

Administrators can directly impact performance of a plant by providing inadequate staffing levels to provide for an operator at the plant when the plant is in operation. Inadequate plant coverage often results in poor performance since no one is at the plant to adjust chemical dosages relative to raw water quality changes. Another area in which administrators can indirectly affect plant performance is through personnel motivation. A positive influence exists if administrators encourage personal and professional growth through support of training, tangible awards for upgrading of certification levels, etc. If, however, administrators eliminate or skimp on essential operator training, downgrade operator positions through substandard salaries, or otherwise provide a negative influence on operator morale, administrators can have a significant detrimental effect on plant performance.

Design Factors

Data gathered during a plant tour, review of plant drawings and specifications, completion of design information forms in Appendix C, and the completed evaluation of major unit process capabilities, including the performance potential graph, provide the basic information needed to assess design-related performance limiting factors. Often, to complete the evaluation, the evaluator must make field investigations of the various unit processes.

Field evaluations or special studies should be completed in cooperation with the plant operator. The evaluator must not make any changes in equipment operation unilaterally. Any field testing desired should be discussed with the operator, whose cooperation should be obtained in making any needed changes. This approach is essential since the evaluator may wish to make changes that could improve plant performance but could be detrimental to equipment at the plant. The operator has worked with the equipment, repaired past failures, and read the manufacturer's literature, and is in the best position to ascertain any adverse impact of proposed changes. Special Studies are discussed in more detail in Section 2.3.3.5.

Operational Factors

Operational factors are those that relate to the unit process control functions. Significant performance limiting factors often exist in these areas (4,10,11). The approach and methods used in maintaining process control can significantly affect performance of plants that have adequate physical facilities.

A plant tour provides an opportunity to initially assess process control efforts. For example, the process control capability of an operator can be subjectively assessed during a plant tour by noting if the operator recognizes the unit process functions and their relative influences on plant performance. A good grasp of process control is indicated if this capability exists.

The heart of the operational factors assessment is the process control testing, data interpretation, and process adjustment techniques utilized by the plant staff. The primary controls available to a water treatment plant operator are flow rate; chemical selection and dosage; and filter backwash frequency, duration and rate. Other controls include flocculation energy input and sedimentation sludge removal. Process control testing is necessary to gain information to make decisions regarding these available controls. Information to assist in evaluating process control testing, data interpretation and process adjustment efforts is presented.

Plant Flow Rate: Plant flow rate dictates the hydraulic loading rate on the various plant unit processes. In plants that operate 24 hours each day, water demand dictates water production requirements. However, many small plants operate at maximum flow rates for short (e.g., 8 hour) periods of time. If the operator is not aware that operating for longer periods of time at a lower flow rate could improve plant performance, an operations factor may be indicated. Rapid increases in plant flow rate can also have a significant effect on plant performance by forcing particles through the filters.

Chemical Dose Control: Chemical coagulants and filter and flocculant aids are utilized to neutralize charges on colloidal particles and to increase the size of the particles to allow them to be removed in sedimentation and filtration unit processes. Either overdosing or underdosing these chemicals can result in a failure to destabilize small particles, including pathogens, and allow them to pass through the sedimentation and filtration processes. If disinfection is inadequate to eliminate the pathogens that pass

through the plant, a significant public health threat exists. Chemicals used for stabilization, disinfection, taste and odor control, and fluoridation must also be controlled.

The following are common indicators that proper chemical dose control is not practiced:

- Calibration curves are not available for chemical feed pumps.
- The operator cannot explain how chemicals, such as polymers, are diluted prior to application.
- The operator cannot calculate chemical feed rates (i.e. cannot convert a desired mg/L dose to a kg/day or mL/min chemical feed rate).
- The operator cannot determine the chemical feeder setting for a required feed rate.
- The operator does not adjust chemical doses for varying raw water quality conditions.
- Chemicals are utilized in combinations that have detrimental effects on plant performance. An example is the practice of feeding lime and alum at the same point without consideration of the optimum pH for alum coagulation.
- Chemical feed rates are not changed when plant flow rate is adjusted.
- Chemical coagulants are not utilized when raw water quality is good (e.g., turbidity less than 1.0 NTU).

Filter Control: The effectiveness of the filtration unit process is primarily established by proper coagulant control; however, other factors, such as hydraulic loading rate and backwash frequency, rate, and duration, also have a significant effect on filter performance. Filters can perform at relatively high filtration rates (e.g. >20 m/h) if the water applied is properly chemically conditioned (12,13). However, because particles are held in a filter by relatively delicate forces, rapid flow rate changes can drive particles through a filter causing a significant degradation in performance (4,12,13). Rapid rate changes can be caused by increasing plant flow by bringing a high volume constant rate pump on-line, by a malfunctioning filter rate control valve, or by removing a filter from service for backwashing without reducing overall plant flow.

Filters must be backwashed periodically to prevent accumulated particles from washing through the filter or to prevent the filter from reaching terminal headloss. Filters should be backwashed based on effluent turbidity if breakthrough occurs before terminal headloss to prevent poor filtered water quality. For example, particles that are initially removed by the filter are often "shed" when velocities and shear forces increase within the filter as headloss accumulates (e.g., filter becomes "dirty"). This significant breakthrough in particles can be prevented by washing a filter based on turbidity or particulate analysis. Inadequate washing, both in terms of rate and duration, can also result in an accumulation of particles in the filter, resulting in poor filtered water quality. When a filter is continually returned to service with a significant amount of particles still within the media, these particles can accumulate to form mudballs. The accumulation of mudballs takes up effective filter surface area and raises the filtration rate through those areas of the filter where water can still pass. The filter can also reach a point where minimal additional particles can be removed because available storage sites within the media already have an accumulation

of filtered particles. The evaluator must determine whether inadequate washing is caused by a design or an operational limitation. Field evaluations, such as bed expansion and rise rate, that can be conducted to determine the capability of backwash facilities are discussed in Section 2.3.3.5. The following are common indicators that proper filter control is not practiced:

- Individual filter performance is not monitored.

- Rapid increases in overall plant flow rate are made without consideration of filtered water quality.

- Filter performance after backwash is not monitored.

- Filters are removed from service without reducing plant flow rate, resulting in the total plant flow being directed to the remaining filters.

- Operators backwash the filters without regard for filter effluent turbidity.

- Operators backwash at a low rate for a longer period of time, or stop the backwash when the filter is still dirty to "conserve" water.

- Filters have significantly less media than specified, damage to underdrains or support gravels, or a significant accumulation of mudballs; and these conditions are unknown to the operating staff because there is no routine examination of the filters.

- The purpose and function of the rate control device cannot be described.

Process Control Activities: It is necessary for the operations staff to develop information from which proper process adjustments can be made. As a minimum, a method of coagulation control must be practiced, such as jar testing. Samples of raw water, settled water and individual filter effluent should be monitored for turbidity. An operator who properly understands water treatment should be able to show the evaluator a recorded history of raw, settled, and filtered water quality and jar test results; and be able to describe how chemical dosages are determined and calculated, and how chemical feeders are set to provide the desired chemical dose. The operator should also be able to explain how chemical feed rates are adjusted, depending on raw water quality.

The following are common indicators that required process control activities are not adequately implemented at a plant:

- Jar tests or other methods (e.g., streaming current monitor, zeta potential, or pilot filter) of coagulation control are not practiced.

- The operator does not understand how to prepare a jar test stock solution or how to administer various chemical doses to the jars.

- The only testing being conducted is raw water turbidity (daily) and finished water turbidity, as collected from a clearwell sample on a daily basis.

- Settled water turbidities are not measured on a routine basis (e.g., minimum of once each shift).

- Individual filtered water quality is not monitored.

- There are no records available documenting performance of the individual sedimentation or filtration unit processes.

Other Controls: Other controls available to the operator include rapid mixing, flocculation energy input, and sedimentation sludge removal. The following are indicators that these controls are not fully utilized to improve plant performance:

- The rapid mixer is shut down (e.g., to conserve power).

- Variable speed flocculation drives are not adjusted (e.g., they remain at the setting established when the plant was constructed).

- There is no routine removal of sludge from sedimentation basins.

- There is no testing to control sludge quantities in a reactor upflow sedimentation basin (e.g., routine sludge withdrawal is not practiced).

Maintenance Factors

Maintenance performance limiting factors are evaluated throughout the CPE by data collection, observations, and questions concerning reliability and service requirements of pieces of equipment critical to plant performance. If units are out of service routinely or for extended periods of time, maintenance practices may be a significant contributing cause to a performance problem. However, equipment breakdowns are often used as excuses for performance problems. For example, one operator blamed excessive turbidity levels from the sedimentation basin on the periodic breakdown of the primary alum feeder. However, the backup feeder, while of greater capacity, could have provided an acceptable alum dose. The real cause of the poor sedimentation basin performance was a lack of understanding by the operator of the importance of maintaining the chemical feed rate.

It is important that maintenance activities be evaluated with respect to their impact on plant performance and not on the basis of comparison to the availability of a documented preventive maintenance program. As such, maintenance would not be identified as a performance limiting factor at a plant that is exhibiting a high degree of performance but has no documented routine maintenance system.

2.2.4 Assessment of Applicability of a CTA

Proper interpretation of the CPE findings is necessary to provide the basis for a recommendation to pursue the performance improvement phase (e.g., CTA described in Chapter 3). It is at this assessment phase that the maximum application of the evaluator's judgment and experience is required. The initial step in assessment of CTA applicability is to determine if improved performance is achievable by evaluating the capability of major unit processes. A CTA is recommended if unit processes receive a Type 1 or Type 2 rating. However, if major unit processes are deficient in capacity, acceptable performance from each "barrier" may not be achievable, and the focus of follow-up efforts must include a more detailed evaluation of options for plant expansion.

Although all performance limiting factors can theoretically be eliminated, the ultimate decision to conduct a CTA may depend on the factors that are identified during the CPE. An assessment of the list of prioritized factors helps assure that all factors can realistically be addressed given the unique set of factors noted. There may be reasons why a factor cannot be approached in a straightforward manner. Examples of issues that may not be feasible to address directly are replacement of key personnel, increases in rate structures or training of uncooperative administrators to support plant needs. In the case of reluctant administrators who do not take water quality seriously, regulatory pressure may be necessary before a decision is made to implement a CTA.

For plants where a decision is made to implement a CTA, all performance limiting factors must be considered as feasible to correct. These are typically corrected with adequate "training" of the appropriate personnel. The training is addressed toward the operational staff for improvements in plant process control and maintenance, toward the plant administrators for improvements in administrative policies and budget limitations, and toward operators and administrators to achieve minor facility modifications. Training, as used in this context, describes activities whereby information is provided to facilitate understanding and implementation of corrective actions.

2.2.5 CPE Report

Results of a CPE are summarized in a brief written report to provide guidance for facility administrators and operators and, if applicable, regulatory personnel. It is important that the report be kept brief so that the maximum amount of resources is used for the evaluation rather than preparing an all-inclusive report. The report should present enough information to allow the decision-making official to initiate efforts toward achieving desired performance from their facility. It should not provide a list of specific recommendations for correcting individual performance limiting factors. Making specific recommendations often leads to a piecemeal approach to corrective actions, and the goal of improved performance is not achieved. For Type 1 and Type 2 plants, the necessity of comprehensively addressing the combination of factors identified by the CPE through a CTA should be stressed. For Type 3 plants, a recommendation for a more detailed study (e.g. process audit) may be warranted. Appendix E includes a sample CPE report.

2.3 HOW TO CONDUCT A CPE

A CPE involves the conduct of numerous activities within a structured framework to determine if significant improvements in treatment performance can be achieved without major capital improvements. A schematic of CPE activities is shown graphically in Figure 2-8.

Initial activities are conducted prior to on-site efforts and involve notifying appropriate utility personnel to ensure that they will be available. The kickoff meeting, conducted on-site, allows the evaluators to describe on-site activities, to coordinate schedules, and to notify personnel of the materials that will be required. Following the kickoff meeting, a plant tour is conducted by the superintendent or process control supervisor. During the tour, the evaluators ask questions regarding the plant and notice items that may require additional attention during data collection activities. For example, an evaluator might make a mental note to investigate more thoroughly the flow splitting arrangement prior to flocculation basins.

Following the plant tour, data collection activities begin. Depending on team size, the evaluators split into groups to facilitate simultaneous collection of the administrative, design, operations, maintenance and performance data. After data are collected, the major unit process evaluation and performance assessment are conducted. Completing these activities prior to the interviews provides the evaluators with an understanding of plant unit process capability and current plant performance, which allows interview questions to be focused on possible factors limiting plant performance. Interviews and special studies are then conducted which allow additional insight to be gained regarding actual plant performance and what factors are contributing to the level of performance observed.

After all information is collected, the evaluation team meets at a location away from the utility personnel to review findings. At this meeting, factors limiting performance of the plant are identified and prioritized. The prioritized list of factors, performance data, and major unit process evaluation data are then compiled and copied for use as handouts during the exit meeting. An exit meeting is held with appropriate operating and administrative personnel where all evaluation findings are presented. Off-site activities include assessing the applicability of a follow-up CTA and completing the written report. A more detailed discussion of each of these activities follows.

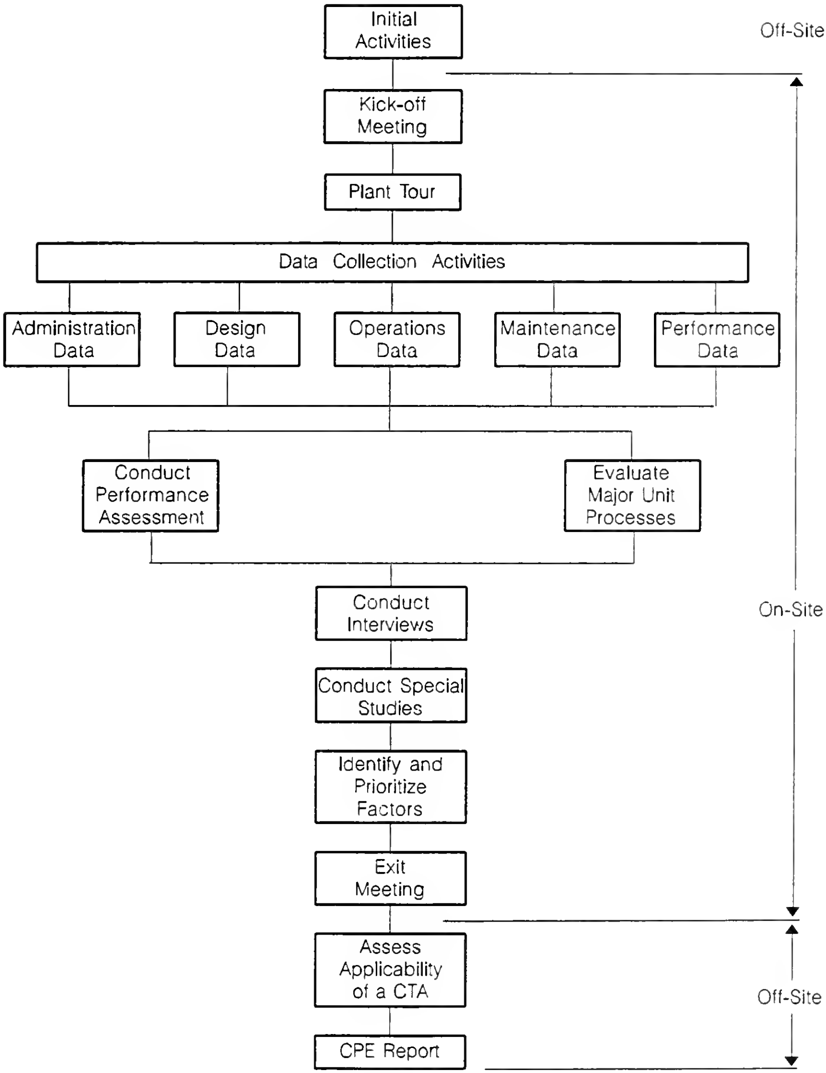
2.3.1 Personnel Capabilities

A CPE is typically conducted over a 3 to 5 day period by a team composed of a minimum of two personnel. The team approach allows a plant to be evaluated in a reasonable time frame and for personnel to share impressions. Shared impressions are especially important when identifying and prioritizing performance limiting factors and in assessing major unit process capability since these efforts require a significant amount of judgment. Persons responsible for conducting CPEs should have significant knowledge and skills in the following areas:

- Regulatory requirements
- Process control
- Coagulation chemistry
- Process design
- Sampling
- Laboratory testing
- Water rate structures
- "People" skills
- Hydraulic principles
- Operator training
- Safety
- Maintenance
- Management
- Utility budgeting
- Interview skills

Regulatory agency personnel with experience in evaluating water treatment facilities and consulting engineers who routinely work with plant evaluation, process design and start-up represent the types of personnel with adequate backgrounds to conduct CPEs. Utilities/municipalities are encouraged to use the services of a consultant with specialized expertise in water plant process design and troubleshooting, as opposed to a consultant whose focus is designing and building plants. It is highly recommended that the firm that originally designed the plant NOT be used for CPE activities, as they are unlikely to critique their own design.

FIGURE 2-6. Schematic of CPE Activities



2.3.2 Initial Activities

To determine the magnitude of the field work required and to make the on-site activities most productive, specific initial information should be gathered. This information includes basic data on the plant and sources for any additional information. If a person associated directly with the plant is the evaluator conducting the CPE, some of the steps may not be necessary.

The following is a list of items that the CPE team should take to the plant. These items will aid in the collection and handling of data and other information.

- MOE Optimization Guidance Manual (i.e. this document) and other reference materials.
- Flow-through turbidimeter with recorder.
- Lap-top computer with spread-sheet capability for analysis/presentation of data.
- Tape measure.
- Filter media probe, with Secchi disk attachment for measuring bed expansion during backwash.
- Camera

2.3.2.1 Identify Key People

It is necessary to have key people available during the conduct of the CPE. Therefore, these people should be identified and their availability determined. The plant superintendent, manager or other person in charge of the water treatment facility must be available. If different persons are responsible for plant maintenance and process control, their presence should also be required. These persons should be available throughout the field activities. A person knowledgeable about details of the utility budget must also be available. A one- to two-hour meeting with this person will typically be required during the field work to assess the financial aspects of the utility. In many small communities, this person is most often the Clerk. In larger communities, the Manager or Plant Superintendent can usually provide the best information.

Availability of key administrative personnel is required. In many small communities, an operator or plant superintendent may report directly to the local Council or Chair of Council. In larger communities, the key administrative person is often the Director of Public Works or other non-elected administrator. In all cases the administrator(s) as well as representative elected officials who have the authority to effect a change in policy or budget for the plant should be available.

If a consulting engineer is currently involved with the plant, that individual should be informed of the CPE and provided with a copy of the report. Normally, the consulting engineer will not be directly involved in the conduct of the CPE. An exception may occur if there is an area of the evaluation that could be supplemented by the expertise available through the consultant.

2.3.2.2 Scheduling

When initiating a CPE, a letter should be sent to the utility describing the schedule of activities that will take place and outlining the commitment required of plant and administrative staff. An example letter is presented in Appendix D. Interviews of personnel associated with the plant are a key component of conducting a CPE. As such, the major criterion for scheduling the time for a CPE should be local personnel availability. If the CPE is conducted by personnel not associated with a regulatory agency, it may be beneficial to inform regulatory personnel of the CPE schedule. Responsibility for this task should be clearly identified by the evaluator and local personnel during the scheduling of activities.

2.3.2.3 Pre-Meeting

It may be beneficial for the municipality/utility to hold a meeting with its operational staff at some time prior to the CPE kickoff meeting. This will familiarize staff with the intent of the CPE and allows them to be better prepared when the CPE begins. By including operators at the earliest stages, they will be more likely to "buy-in" to the CPE process.

2.3.3 On-Site Activities

On-site CPE activities are largely devoted to collection and evaluation of data. As a courtesy to the facility owner and to promote efficient data collection, the field work is initiated with a kickoff meeting. This activity is followed by a plant tour (conducted by senior operations staff) and a period of time where detailed data on the plant are gathered and analyzed.

2.3.3.1 Kickoff Meeting

A short (less than 30 minutes) meeting between key plant operating and administrative staff and the evaluators should be held to initiate the field work. The major purposes of this meeting are to present the objectives of the CPE effort, to coordinate and establish the schedule, and to initiate the administrative evaluation activities. Each of the specific activities that will be conducted during the on-site effort should be described. Meeting times for interviews with non-plant and plant personnel should be scheduled. A sign-up sheet (see Appendix C) may be used to record attendance and as a means of assisting with recall of names.

Information and resource requirements should be established. Specific items that are required and may not be readily available are: budget information to provide a complete overview of costs associated with water treatment; a water rate schedule; historical monitoring data for a one year period; plant O & M Manuals, if available; and any facility drawings and specifications or other engineering studies available for the existing facilities.

Administrative factors that may affect plant performance should be noted during this meeting, such as the priority of high quality finished water, familiarity with plant needs, communication between administration and plant staff, and policies on plant funding. These initial perceptions often prove valuable when formally evaluating administrative factors later in the CPE effort.

2.3.3.2 Plant Tour

A plant tour should follow the kickoff meeting. The objectives of the tour are to familiarize the evaluator with the physical plant, make a preliminary assessment of operational flexibility of the existing processes and chemical feed systems, and provide an initial basis for discussions on performance, process control and maintenance. A walk-through tour following the flow from the raw water source through the plant to the clearwell is suggested. It is then appropriate to tour backwash and sludge treatment and disposal facilities, followed by the support facilities, such as the laboratory and maintenance areas. The evaluator should note the sampling points and chemical feed locations throughout the plant.

During the conduct of a plant tour the evaluator must be sensitive to the plant personnel conducting the tour. Questions that challenge current operational practices or that put plant personnel on the defensive should be avoided. The evaluator should maintain an information gathering posture at all times. It is not appropriate to recommend changes in facilities or operational practices during the plant tour although the evaluator will often be asked for an opinion. A desired response is to state that observations will be presented at the conclusion of the on-site activities and after additional information is collected and analyzed. Most of the questions asked on the plant tour will be asked again during formal data collection activities. The staff should be informed that this repetitiveness will occur. The plant tour also provides an excellent opportunity for the evaluator to observe intangible items that may contribute to the identification of factors limiting performance (i.e., operator knowledge of the plant operation and facilities, relationship of process control testing to process adjustments, etc.). Suggestions to help the evaluator meet the objectives of the plant tour are provided in the following sections.

Pretreatment

Pretreatment facilities consist of raw water intake structures, screening equipment, raw water pumps, presedimentation basins and flow measurement equipment. Intake structures and screening equipment can have a direct impact on plant performance. For example, if the intake configuration is such that screens become clogged with plant growth or the intake becomes clogged with silt, consistent supply of water may be a problem. While at the raw water source, questions should be asked regarding variability of the raw water quality, potential upstream pollutant sources, seasonal problems with taste and odors, raw water quantity limitations, and algae blooms.

Raw water pumping should be evaluated regarding the ability to provide a consistent water supply and with respect to how many pumps are operated at a time. Frequent changing of high volume constant speed pumps can cause significant hydraulic surges to downstream unit processes, such as filters, degrading plant performance. In addition, operational practices as they relate to peak flow rates, peak daily water production, and plant operating hours should be discussed to assist in defining the peak instantaneous operating flow rate.

Presedimentation facilities are primarily found at water treatment plants where raw water turbidities exceed several hundred NTUs. If plants are equipped with presedimentation capability, basin inlet and outlet configurations should be noted and the ability to feed coagulant chemicals should be evaluated. Typically, most presedimentation configurations lower turbidities enough to allow conventional water treatment plants to perform adequately. If presedimentation facilities do not exist, the evaluator must assess the capability of existing water treatment unit processes to remove peak raw water turbidities.

Flow measurement facilities are important to accurately establish chemical feed rates, wash water rates, and unit process loadings. The plant tour should be used to observe the location of flow measurement equipment and to ask questions regarding various plant flows. Questions should be asked concerning maintenance and calibration of flow measurement devices.

Mixing/Flocculation/Sedimentation

Rapid mixing is utilized to provide a complete instantaneous mix of coagulant chemicals to the water. The coagulants neutralize the negative charges on the colloidal particles allowing them to agglomerate into larger particles during the gentle mixing of flocculation. These heavier particles are then removed by settling in the quiescent area of the sedimentation basin. These facilities provide the primary barrier to pathogens and, if properly designed and operated, reduce the particulate load to the filters, allowing them to "polish" the water. During the tour, observations should be made to determine if the mixing, flocculation, and sedimentation unit processes are designed and operated to achieve this goal. The evaluator should also observe flow splitting facilities and determine if parallel basins are receiving equal flow distribution.

Rapid mix facilities should be observed to determine if adequate mixing of chemicals is occurring. The operator should be asked what coagulant aids are being added and what process controls are employed to determine their dosage. Observations should be made as to the types of chemicals that are being added together in the mixing process. For example, the addition of alum and lime at the same location may be counter productive if no consideration is given to maintaining the optimum pH for alum coagulation. If coagulant chemicals are added without mixing, observations should be made as to possible alternate feed locations, such as prior to valves, orifice plates or hydraulic jumps, where acceptable mixing might be achieved.

When touring flocculation facilities, the evaluator should note inlet and outlet conditions, number of stages, and the availability of variable energy input. Flocculation facilities should be baffled to provide even distribution of flow across the basin and to prevent velocity currents from disrupting settling conditions in adjacent sedimentation basins. If multiple stages are not available, the capability to baffle a basin to create additional staging should be observed. The ability to feed flocculation aids to the gentle mixing portion of the basin should be noted. The operator should be asked how often flocculation energy levels are adjusted or if a special study was conducted to determine the existing levels. In the case of hydraulic flocculation, the number of stages, the turbulence of the water, and the condition of the floc should be noted to determine if the unit process appears to be producing an acceptable floc.

Sedimentation basin characteristics that should be observed during the tour are visual observations of performance and observations of physical characteristics such as configuration and depth. Performance observations include clarity of settled water, size and appearance of floc, presence of floc carryover, and presence of flow or density currents. The general configuration, including shape, inlet conditions, outlet conditions, and availability of a sludge removal mechanism should be observed. The operator should be asked what process control measures are utilized to optimize sedimentation including sludge removal.

Filtration

Filters are utilized to remove the particles that are too small to be removed in sedimentation basins by gravity settling. The number and configuration of filters should be noted, including the type of filter

media. The filter rate control equipment should be observed and discussed to ensure that it regulates filter flow in an even, consistent manner without rapid fluctuations. The flow patterns onto each filter should be noted to see if there is an indication of uneven flow to individual filters. Backwash equipment including pumps, air compressors, and surface washers should be noted. The availability of back-up backwash pumping is desirable to avoid interruptions in treatment if a breakdown occurs. The operator should be asked how frequently filters are backwashed and what process control procedures are used to determine when a filter should be washed. Preferably turbidity, rather than headloss or filter run duration, should be the parameter utilized since it relates to water quality. The operator's response to these inquiries helps to demonstrate his understanding and priorities concerning water quality. The operators should also be questioned concerning the backwash procedure and if all operators follow the same technique.

Disinfection

The evaluator should tour disinfection facilities to become familiar with the equipment feed points, and type of contact facilities. Special attention should be given to the configuration and baffling of clearwells and finished water reservoirs that provide contact time for final disinfection. Observation of the in-line contact time availability should be made by noting the proximity of the "first user" to the water treatment plant.

The availability of back-up disinfection equipment should be observed to assess capability of providing an uninterrupted application of disinfectant. The addition of a disinfectant prior to filtration, either as an oxidizing agent or disinfectant, should also be noted. The capability to automatically control the disinfection systems by flow pacing should be determined.

Backwash Water and Sludge Treatment and Disposal

During the tour, the evaluator should become familiar with the facilities available to handle filter backwash water and sedimentation basin sludge. If backwash water and sludge are discharged to the storm sewer system or a waterway, questions should be asked to determine if the discharge is permitted and if Certificate of Approval requirements are being complied with.

The location of any recycle streams should be identified during the tour. Recycle of backwash water should be assessed relative to the feasibility of returning a potentially high concentration of cysts to the plant raw water stream. Cysts are primarily removed by the filters so that the recycle of backwash water in a plant where the raw water has a high potential for substantial numbers of cysts may compound the health risk, depending on washwater treatment.

Laboratory

The laboratory facilities should be included as part of the plant tour. Performance monitoring, process control testing, and quality control procedures should be discussed with laboratory personnel. It is especially important to determine if turbidity measurements represent actual plant performance. Available analytical capability for other parameters (e.g. pH, chlorine residual) should also be noted.

Maintenance

Maintenance facilities should be included as part of the plant tour. Tools, spare parts availability, storage, filing systems for equipment catalogs, general plant appearance and condition of equipment should be observed. Questions on the preventive maintenance program, including methods of initiating work (e.g., work orders), are appropriate.

2.3.3.3 Detailed Data Gathering

Following the plant tour, formalized data collection procedures are initiated. Information is collected through conducting interviews with plant and administrative staff; reviewing plant records, drawings, specifications, process control data sheets, etc.; and conducting field evaluations.

2.3.3.4 Plant Records

A variety of plant records including budgets, drawings and specifications, MOE Drinking Water Surveillance Program (DWSP) reports, MOE Sewage and Water Inspection Program (SWIP) reports, operational logs, O & M Manuals, and manufacturers' literature are required for the formal data collection efforts. The forms in Appendix C have proven to be valuable in compiling information from these multiple sources in a consistent manner. Categories covered by these forms are listed below:

- Kickoff Meeting
- Administration Data
- Design Data
- Operations Data
- Maintenance Data
- Performance Data
- Interview Data
- Exit Meeting

When collecting information, the evaluator should be aware that the data are to be used to evaluate the performance capability of the existing facilities. The evaluator should continuously be asking "How does this information affect plant performance?". If the area of inquiry is directly related to plant performance, such as filter design or an indication of an administrative policy to cut costs by reducing chemical addition, the evaluator should spend sufficient time to fully develop the perceived effect of the information on plant performance.

2.3.3.5 Field Evaluations

Field evaluations are an important means of identifying performance problems. Typically, field evaluations should be conducted to verify accuracy of monitoring and flow records, chemical dosages, drawings, filter integrity, and backwash capability.

Performance monitoring records can be verified by measuring turbidities from an individual filter and the clearwell. It is important that the evaluator provide properly calibrated turbidimeters to support this field effort. A recording on-line turbidimeter or an instrument that allows individual analysis of grab samples can be used. Treated water quality obtained from the field evaluation can be compared with the recorded

data to make a determination if performance monitoring records accurately represent treated water quality. Differences in actual versus recorded finished water quality can be caused by sampling location or sampling time. The evaluator's instrument can also be used to assess the plant's turbidimeter and calibration techniques.

The accuracy of flow records can be verified by assessing the calibration of flow measurement equipment. This is often difficult because the type of meters utilized (e.g., propeller, venturi, orifice plates, magnetic, etc.) require a basin to be filled or drawn down to accurately check the metering equipment. If accuracy of metering equipment is impossible to field verify, the frequency of calibration of the equipment by the plant staff or outside instrumentation technicians can be evaluated. If flow metering equipment is being routinely (e.g., quarterly or semiannually) calibrated, flow records typically can be assumed to be accurate.

Dosages of primary coagulant chemicals should be verified. Feed rates from dry feeders can be checked by collecting a sample for a specified time and weighing the accumulated chemical. Similarly, liquid feeders can be checked by collecting a sample in a graduated cylinder for a specified time. In both cases the kg/day or mL/min of chemical should be converted to mg/L and compared with the reported dosage. During this evaluation the operating staff should be asked how they conduct chemical feed calculations, prepare polymer dilutions, and make chemical feeder settings.

The integrity of the filter media, support gravels, and underdrain system should be evaluated. This requires that the filter be drained and that the evaluator inspect the media. The filter should be investigated for surface cracking, mudballs, proper media depth, and the occurrence of sand (in a dual media filter) or gravel on the top of the filter. Mudballs can be fished out of the media during backwash by hand or using a net with an appropriate size of mesh. They are also sometimes visible on top of the media. The filter should also be probed with a steel rod to check for displacement of the support gravels. Variations in depth of over 5 cm could signify a problem. Clearwells can also be inspected for the presence of media, which would indicate underdrain damage. A more detailed study of the filter would then be indicated, which is beyond the scope of a CPE.

Filter backwash capability can be field-verified by assessing either the backwash rate or bed expansion. The backwash rate (i.e. rise rate) can be determined by measuring the rise of water in the filter compartment over a specific time. For example, a filter would have a backwash rate of 48.6 $m^3/m^2/h$ if the water rose 27 cm in 20 seconds. This technique is not suitable for filters where the peak backwash rate is not reached until the washwater is passing over the troughs.

Bed expansion is determined by measuring the distance from the top of the unexpanded media to a reference point (e.g. the top of a filter wall) and from the top of the expanded media to the same reference point. The difference divided by the total depth of media multiplied times 100 gives the percent bed expansion. A proper wash rate should expand the filter media a minimum of 25 percent (1,5).

Record drawings may have to be field verified by measuring basin dimensions with a tape measure if there is doubt as to their accuracy. If no drawings are available, all basin dimensions will have to be measured.

2.3.3.6 Evaluation of Major Unit Processes

An evaluation of the plant's major unit processes is conducted to determine the performance potential of existing facilities at peak instantaneous operating flow. This is accomplished by developing a performance

potential graph and rating the major unit processes as Type 1, 2, or 3, as discussed in Section 2.2.1. It is important that the major unit process evaluation be conducted early in the on-site activities since this assessment provides the evaluator with the knowledge of the plant's treatment capability. If a poorly performing plant's major unit processes are determined to be Type 1 or 2, then typically factors in the areas of administration, operation or maintenance are primarily contributing to the performance problems. The completed major unit process assessment allows the evaluator to focus later interviews and data gathering to identify those performance limiting factors.

2.3.3.7 Performance Assessment

An assessment of the plant's performance is made by evaluating existing recorded data and by conducting on-site evaluations to determine if unit process and total plant performance have been optimized. Typically, the most previous twelve months of existing process control data is evaluated and graphs are developed to assess performance of the plant. Other periods of process control data can be evaluated if they are more representative of plant operating conditions. Field evaluations are also conducted to determine if existing plant records accurately reflect actual plant treated water quality. A detailed discussion of the methods utilized in the performance assessment is presented in Section 2.2.2.

2.3.3.8 Interviews

It is beneficial to complete filling out the data collection forms and to complete the major unit process evaluation and performance assessment before initiating the formalized interviews, since this background information allows the evaluator to better focus interview questions. Interviews should be conducted with all of the plant staff, including the superintendent and other key administrative personnel. Key administrators typically include a Council or Board member (especially from a Water Committee), and the Utility Director/Manager. The interviews should be conducted privately with each individual. Approximately 30 minutes should be allowed for each interview.

Interviews are conducted to clarify information obtained from plant records and to ascertain differences between real or perceived problems. Intangible items such as communications, administrative support, morale, and work attitudes are also assessed during the interview process. Administrative and plant staff are both interviewed in order to obtain both sides of the story. The performance focus of the CPE process must be maintained in the interviews. For example, an adamantly stated concern regarding supervision or communication is only of significance if it can be directly related to plant performance.

2.3.3.9 Evaluation of Performance Limiting Factors

After all data has been gathered, the major unit process evaluations have been completed, plant performance has been assessed, and formal interviews have been completed, identification and prioritization of performance limiting factors should be conducted. The identification of factors should be completed at a location that allows open and objective discussions to occur (i.e. away from plant staff). Prior to the discussion, a debriefing session should be held that allows the evaluators to discuss pertinent findings from their respective efforts. This step is especially important if more than two evaluators are involved in the CPE because, with larger evaluation teams, not all members can be exposed to every aspect of the comprehensive evaluation. All data compiled during the evaluations should be readily available to support the factor identification efforts.

The checklist of performance limiting factors presented in Appendix B, as well as the factor definitions, provides the structure for an organized review of problems in the subject plant. The intent is to identify, as clearly as possible, the factors that most accurately describe the causes of limited performance. Often a great deal of discussion is generated in this phase of the CPE effort. Several hours should be allocated to complete this step and all opinions and perceptions should be solicited. It is particularly important to maintain the performance focus during the activity in order to avoid identifying factors that do not have this emphasis.

Each factor identified as limiting performance should be assigned an "A", "B", or "C" rating. Further prioritization is accomplished by completing the Summary Sheet presented in Appendix B. Only those factors receiving either an "A" or "B" rating are prioritized on this sheet. Additional guidance for identifying and prioritizing performance limiting factors is provided in Section 2.2.3.

2.3.3.10 Exit Meeting

Once the evaluation team has completed the field work for the CPE, an exit meeting should be held with the plant administrators and staff. A presentation of preliminary CPE results should include brief descriptions of the following:

- Plant performance assessment;
- Evaluation of major unit processes;
- Prioritized performance limiting factors;
- Plant performance potential.

Handouts, typically handwritten, summarizing these topics can be utilized to assist in the exit meeting presentation. Handouts typically utilized to present performance assessment findings are time versus turbidity plots (one year of data) and percentile plots for raw, settled and finished water, and results of field evaluations such as turbidity profiles following a filter backwash. The performance potential graph and factor summary sheet can be utilized to present information regarding the major unit process evaluation and performance limiting factors, respectively.

If the CPE reveals that the treatment plant performance represents a significant health impact, this should be carefully explained to the utility staff. Regulatory personnel conducting such a CPE should determine if administrative or regulatory action should be implemented. If a utility is operating within applicable turbidity objectives, but not optimizing treated water quality, a presentation can be made as to the potential health advantage of setting more aggressive goals such as a finished water turbidity of less than 0.1 NTU. A brief presentation on the function of each water treatment unit process and the effort required to produce acceptable finished water quality can also be made to enhance water treatment understanding for the administrators.

It is important to present all findings at the exit meeting with local officials. This approach eliminates surprises when the CPE report is received and lays the foundation for the approach necessary for any follow-up activities. In situations where administrative or operating staff shortcomings are difficult to present, the evaluator must be sensitive and use communication skills to successfully present the results. Throughout the discussions, the evaluator must remember that the purpose of the CPE is to identify and describe facts to be used to improve the current situation, not to place blame for any past or current problems.

It is emphasized that findings, and not recommendations, be presented at the exit meeting. The CPE, while comprehensive, is conducted over a short time and is not a detailed engineering design study. Recommendations made without appropriate follow-up could confuse operators and administrators, and lead to inappropriate or incorrect actions on the part of the utility staff (e.g., improper technical guidance). For example, a recommendation to set coagulant dosages at a specific level could be followed literally to the extent that the next time the evaluator is at the plant, coagulant dosages may still be the same as that recommended even though time and highly variable raw water conditions have passed.

It should also be made clear at the exit meeting that other factors are likely to surface during the conduct of any follow-up activities. These factors will also have to be addressed to achieve the desired performance. This understanding of the short term CPE evaluation capabilities is often missed by local and regulatory officials, and efforts may be developed to address only the items prioritized during the CPE. The evaluator should stress that a commitment must be made to achieve the desired improved performance, not to addressing a "laundry list" of currently identified problems. An ideal conclusion for an exit meeting is that the facility owners fully recognize their responsibility to provide a high quality finished water and that, armed with the findings from the CPE, they are enthusiastic to pursue achievement of this goal.

2.3.4 CPE Report

At the conclusion of the field activities, a CPE report is prepared. The objective of a CPE report is to summarize findings and conclusions (see Section 2.2.5.). Eight to twelve typed pages are generally sufficient for the text of the report. An example report is presented in Appendix E. Typical contents are:

- Introduction
- Facility Information
- Major Unit Process Evaluation
- Performance Assessment
- Performance Limiting Factors
- Projected Impact of a CTA

As a minimum, the CPE report should be distributed to plant administrators and all plant personnel. Further distribution of the report (e.g., to the design engineer) depends on the circumstances of the CPE, but should be done at the direction or with the awareness of local administrators.

2.4 EXAMPLE CPE

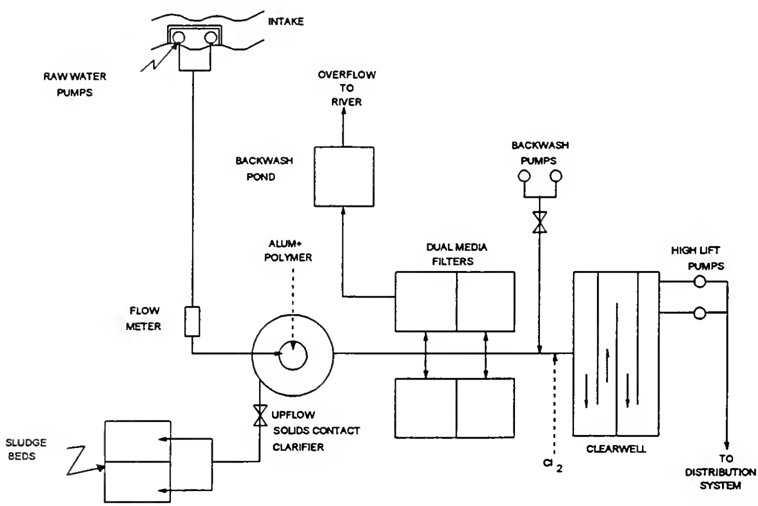
This is an example of a CPE conducted in the U.S. Although the situation is different in Ontario in terms of regulatory issues, the concepts of a CPE are well illustrated.

An 10,000 m^3/d (2.2 MIGD) conventional plant consisting of an upflow solids contact clarifier and dual media filtration serves a residential community with a population of 12,000. The regulatory agency identified in their review of routine monitoring reports that finished water turbidities were periodically slightly above the 1.0 NTU limit. The agency notified the community that they were going to conduct a CPE to determine if there was a performance problem and, if so, to determine the causes of the poor performance.

2.4.1 Facility Information

A flow schematic of the plant is presented in Figure 2-7. The following data were compiled from the completed data collection forms, as presented in Appendix C. The plant was being operated at 10,000 m^3/d (6,950 L/min.) (one raw water pump) for the length of time required to fill the storage reservoir, which was approximately five hours per day in winter and ten hours per day during summer.

Figure 2-7. Flow Schematic of Plant in CPE Case Study



Design Flow: 10,000 m^3/d (2.2 MIGD)

Peak Instantaneous Operating Flow: 10,000 m^3/d (6,950 L/min)

Average Daily Flow: 2,500 m^3/d (0.55 MIGD)

Peak Daily Flow: 4,500 m^3/d (1.0 MIGD)

Raw Water Intake: Two vertical turbine pumps at 10,000 m^3/d (6,950 L/min.) each

Flow Measurement: Propeller meter with strip chart recorder

Sedimentation: Number: 1
(Clarifier)Type: Solids contact
Settling Area: 100 m^2 (1,075 ft^2)
Depth: 4 m (13 ft) with 45° tube settlers

Filtration: Number: 4 Type: Dual media
Dimensions: 3.7 m x 3.7 m (12 ft x 12 ft)
Area: 13.4 m^2 (144 ft^2) per filter

Clearwell: 530 m^3 (117,000 IG) baffled basin

Chemical: Feed Two dry alum feeders each rated at 57 to 1,134 kg/d (125 to 2,500 lb/d).

Two polymer feed systems each with a 189 L (42 IG) dilution tank and a 63 to 347 mL/min. (0.8 to 4.6 IG/hr) pump.

Two gas chlorination systems (post chlorination only), each rated at 57 kg/d (125 lb/d).

High Lift: Two vertical turbine pumps at 10,000 m^3/d (6,950 L/min.) each.

2.4.2 Major Unit Process Evaluation

A performance potential graph (Figure 2-8) was prepared to assess the capability of the facility's major unit processes. The calculations that were conducted to complete the graph and major unit process evaluation are shown below.

Sedimentation

Settling Area = 100 m^2

Rated by evaluator at 59 $m^3/m^2/d$ based on professional judgement (from Table 2-1)

Rated Capacity = 59 $m^3/m^2/d$ x 100 m^2 = 5,900 m^3/d

Filtration

Filtration Area = 4 x 3.7 m x 3.7 m = 54 m^2

Rated by evaluator at 117 $m^3/m^2/d$ rather than 235 $m^3/m^2/d$ because of observed air binding at higher rates (from Table 2-1).

Rated Capacity = 117 $m^3/m^2/d$ x 54 m^2 = 6,318 m^3/d

<u>Disinfection</u>

Estimate required log reduction of *Giardia* cysts based on surface water quality.

Use 4 log reduction because river supply has wastewater discharges upstream.

Estimate the log reduction removal credit for the existing plant.

Allow 2.5 log reduction of *Giardia* cysts for conventional filtration plant (see Table 2-2). Therefore, 1.5 logs of inactivation (4.0 - 2.5) is required in final disinfection.

Select CT value (see Appendix A).

Finished water pH = 7.5
Minimum temperature = 0.5 °C
Maximum free chlorine residual acceptable = 2.5 mg/L
Selected CT = 150 mg-min/L from Appendix A.

Calculate effective volume for contact.

Clearwell is the only available volume for contact because first customer tap is adjacent to plant. Backwash lowers clearwell depth to one-half of full depth. Evaluate basin at minimum depth; therefore, use half of 530 m^3 basin.

Use factor of 0.9 based on serpentine baffling throughout basin (see Table 2-3) and factor of 0.5 to account for minimum water depth.

Effective basin volume = 0.9 x 0.5 x 530 m^3 = 238 m^3

Calculate required detention time.

Required HDT = 150 mg/L-min ÷ 2.5 mg/L = 60 min.

Calculate required rate of flow to achieve detention time of 60 minutes.

Rated Capacity = 238 m^3 ÷ 60 min = 3.97 m^3/min = 5,712 m^3/d

As shown in Figure 2-8, the limiting unit process is disinfection, which was rated at 5,712 m^3/d. This is less than 90 percent of the actual peak instantaneous operating flow rate of 10,000 m^3/d), which indicates a Type 3 rating. The type ratings for all unit processes are shown in Table 2-5. As shown, all unit processes were rated Type 3 because they were assessed to have a capacity less than 90 percent of the actual peak instantaneous operating flow of 10,000 m^3/d). Further evaluation of flow records and operating times revealed that the plant could be easily operated for longer periods of time each day and that the peak flow could be kept at 5,712 m^3/d or less, which would result in all major unit processes achieving 100 percent of the established peak instantaneous operating flow. Therefore, the maximum flow (peak instantaneous operating flow) that the plant would successfully operate at was established at 5,700 m^3/d, resulting in a Type 1 rating for all unit processes (see Table 2-5).

TABLE 2-5. Rating of the Unit Processes and Overall Plant for the Example CPE

Unit Process	Rating	
	10,000 $m^3/d^{(*)}$	5,700 m^3/d
Sedimentation	Type 3	Type 1
Filtration	Type 3	Type 1
Disinfection	Type 3	Type 1

(*) Peak instantaneous flowrate.

2.4.3 Performance Assessment

The performance assessment conducted using plant records indicated that the finished water turbidity rarely exceeded 1.0 NTU but that the plant would not achieve the proposed new SWTR requirement that 95 percent of the samples collected each month have a turbidity less than 0.5 NTU. The settled water turbidity averaged about 10 NTU. Special studies conducted of the filter effluent turbidity revealed a turbidity spike of 3.5 NTU when the plant was started in the morning with dirty filters and of 4.8 NTU following a backwash. The turbidities in both cases dropped to about 0.8 NTU following an hour of operation.

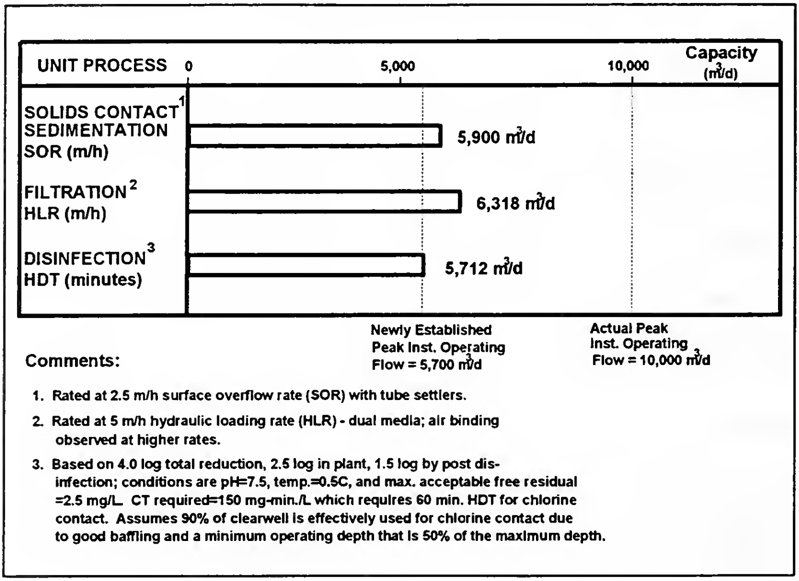
2.4.4 Performance Limiting Factors

The following performance limiting factors were identified during the CPE and were given ratings of "A" or "B". Further prioritization of these factors was also conducted, as indicated by the number assigned to each factor.

1. Application of Concepts and Testing to Process Control - Operation (A)

The plant operators had established no process control program to make decisions regarding plant flow rate, coagulant dose and filter operation. Coagulant dosages were approximately 200 percent higher than desired and no jar tests or other means were used to determine appropriate dosages. Filters were started dirty on a routine basis and the plant was operated at maximum capacity when a much lower rate was possible. Filter effluent and clearwell turbidities during the CPE were often found to be above 1 NTU, but samples were routinely collected at the clearwell prior to plant start-up and thus the excursions above 1.0 NTU were not evident in plant records. These practices showed little awareness of the importance of producing high quality treated water on a continuous basis.

FIGURE 2-8. Performance Potential Graph for CPE Case Study.



2. Process Control Testing - Operation (A)

The only process control testing that was conducted was turbidity on daily grab samples of raw water and treated water from the clearwell and chlorine residual on treated water after the high service pumps. No process control testing was done to control the reactor clarifier, coagulant dosages, or filtration. As such, there was limited information available to make process control decisions.

3. Plant Coverage - Administration (A)

Plant operators were only allowed enough time to be at the plant approximately one hour each day. This allowed a periodic check of equipment; however, frequently raw water quality would vary and not be noticed for up to 24 hours, resulting in periods of poor treated water quality. On occasion, the alum feed line would plug and go unnoticed, resulting in periods of poor treated water quality. The operators were expected to conduct other activities, such as monitoring the town swimming pool, assisting wastewater treatment plant operators, and assisting street maintenance crews during summer months.

4. Sedimentation - Design (B)

The sedimentation basin was not capable of adequately removing suspended particles at flows above 5,900 m^3/d. Reducing the flow would allow the basin to perform adequately during most periods of the year, but the basin could limit plant performance when raw water turbidities exceeded 500 NTU periodically during spring run-off.

5. Filtration - Design (B)

The filters were limited by severe air binding during winter months that increased the frequency of backwash. The air binding problem should be relieved by reducing the hydraulic loading on the filters; however, periodic air binding may limit plant performance.

6. Disinfection - Design (B)

Operation of the plant at maximum flow rate will not allow sufficient contact time for disinfection. However, operation of the plant at or below 5,712 m^3/d by increasing the daily time of operation should allow disinfection in compliance with the proposed SWTR regulations to be achieved.

7. Process Controllability/Flexibility - Design (B)

The filter rate controllers were malfunctioning, causing periodic increases in filtered water turbidity. The plant also had no capability of feeding a filter aid.

2.4.5 Assessing Applicability of a CTA

The most serious of the performance limiting factors identified were process control oriented. The evaluation of major unit processes resulted in a Type 3 rating at the present peak instantaneous operating flow. However, it was determined that the rating could be upgraded to Type 1 if the plant peak instantaneous operating flow rate could be reduced by operating for longer periods of time each day. This adjustment will require addressing the plant coverage factor by convincing administrators to allow operators to spend additional time at the treatment facility. If plant flow can be reduced and operator coverage increased, it appears that the utility would be able to achieve improved performance through implementation of a follow-up CTA. This recommendation should be made to the Town Council. Documentation of improved performance may be difficult because existing monitoring data does not reflect true past performance. However, improvement in the turbidity spike after dirty filter start-up and backwashing should be able to be documented. Settled water turbidity should also be reduced to the 1 to 2 NTU range from the present 10 NTU, thus enhancing the treatment barrier this unit process provides.

2.4.6 CPE Results

The success of conducting CPE activities can be measured by plant administrators selecting an approach and implementing activities to achieve the required performance from their water treatment facility. If definite follow-up activities are not initiated within a reasonable time frame, the objectives of conducting a CPE have not been achieved. Ideally, follow-up activities must comprehensively address the combination of factors identified (e.g., implement a CTA) and should not be implemented in a piecemeal approach. In the previous example, plant administrators decided to hire an operations consultant to implement a CTA. The CTA addressed the identified factors and resulted in the existing plant achieving required performance without major capital improvements.

2.5 REFERENCES

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3. COMPREHENSIVE TECHNICAL ASSISTANCE

3.1 OBJECTIVE

The objective of Comprehensive Technical Assistance (CTA) is to achieve a desired level of performance from an existing water treatment facility without major modifications. If the results of a Comprehensive Performance Evaluation (CPE) indicate a Type 1 plant (see Figure 2-1), then existing major unit processes have been assessed to be adequate to meet current treatment requirements. For Type 1 facilities, major plant modifications are not indicated and the CTA can focus on systematically addressing identified performance limiting factors to achieve the desired finished water quality.

For Type 2 plants, existing major unit processes have been determined to be marginal. Improved performance is likely through the use of CTA; however, the plant may or may not meet performance objectives without major facility modifications. For these plants, the CTA focuses on obtaining optimum capability of existing facilities. If the CTA does not achieve the desired finished water quality, unit process deficiencies will be clearly identified and plant administrators can be confident in pursuing the indicated facility modifications.

For Type 3 plants, major unit processes have been assessed to be inadequate to meet performance objectives. For these facilities, major construction is indicated and a comprehensive study that focuses on alternatives to achieve these construction needs is warranted. A study of this type should look at long term water needs, raw water source or treatment alternatives, and financing mechanisms. If existing plant performance has the potential to cause a serious public health risk, officials may want to address the most serious operating problems to reduce the risk until modifications can be implemented.

3.2 CTA METHODOLOGY

The methodology for conducting CTA is a combination of 1) utilizing CPE results as a basis for follow-up, 2) implementing process control priority setting techniques and 3) maintaining long term involvement to systematically train staff and administrators responsible for water treatment.

3.2.1 CPE Results

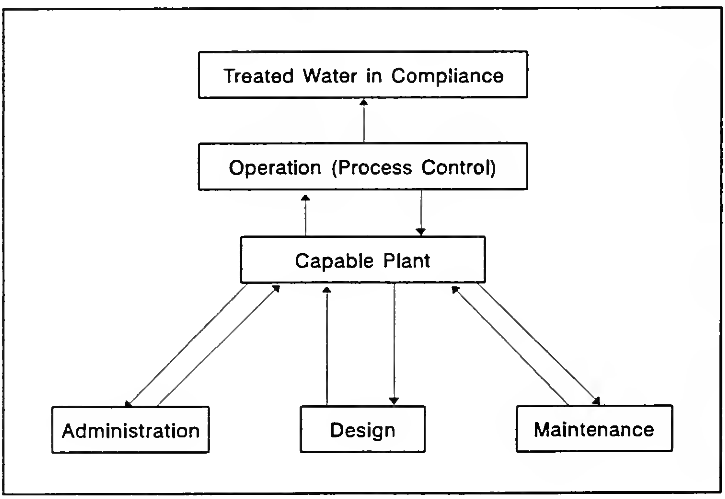
Implementation of a CTA initially focuses on addressing the prioritized list of performance limiting factors that is developed during a CPE. This list provides a plant-specific outline of those items that must be addressed if desired performance is to be achieved. A combination of activities such as training, minor modifications, and process control adjustments may all be used by the person implementing the CTA to address identified factors. It is important to note that additional performance limiting factors, not identified in the short duration of the CPE, often become apparent during conduct of the CTA. These factors must be addressed to achieve the desired level of performance.

3.2.2 Process Control Priority Setting Basis

The areas in which performance limiting factors have been broadly grouped (administration, maintenance, design, and operation) are all important in that a factor in any one of these areas can individually cause poor performance. However, when implementing the CTA the relationship of these categories to achieving the goal of desired finished water quality must be understood. Administration, design and maintenance activities all lead to a plant physically capable of achieving desired performance. It is the operation, or more specifically the process control activities, that enables a physically capable plant to produce adequately treated water. This concept is illustrated graphically in Figure 3-1. Focusing on process control efforts when implementing the CTA allows priorities to be developed for making required changes to achieve improved performance. In this way the most direct approach to improve performance is implemented.

For example, if filtered water turbidities cannot be consistently maintained at required levels because operating staff is not at the plant to make chemical feed adjustments in response to changing raw water quality, then improved performance will require better staff coverage. In this case, identified limitations in meeting process needs (e.g., limitations in making chemical feed adjustments) establish the priority for improving staff coverage (e.g., an administrative policy) at the plant. Additional staff would alleviate the identified deficiency (e.g., provide a capable plant) and allow process adjustments to be made, so that progress toward the performance goal can be continued. Conversely, non-performance related improvements can be justifiably delayed utilizing the same process control emphasis.

FIGURE 3-1. Relationship of Performance Limiting Factors to Achieving a Performance Goal.



3.2.3 Long Term Involvement

To be effective, implementation of the CTA must constitute a long term effort, typically involving several months, for several reasons:

Greater Effectiveness of Repetitive Training Techniques: Operator and administrator training can be conducted under a variety of actual operating conditions (e.g., seasonal water quality or demand changes). This approach allows development of observation, interpretation, and implementation skills necessary to maintain desired finished water quality during periods of variable raw water quality.

Time Required to Make Minor Facility Modifications: For changes requiring financial expenditures, both time and a multiple step approach are typically required to gain administrative (e.g. Local Council) approval. First, the need for minor modifications must be demonstrated through process control efforts. Then council/administrators must be shown the need and ultimately convinced to approve the funds necessary for the modifications. These activities normally take several months before the identified modification is implemented and operational. In addition, depending on the nature of the modifications, an amendment to the plant's Certificate of Approval may be required. This could take several weeks.

Time Required to Make Administrative Changes: Administrative factors can prolong CTA efforts. For example, if the utility rate structure is inadequate to support plant performance, extensive time can be spent implementing required changes in the rate structure. Communication barriers between "downtown" and the plant or between staff members may have to be addressed for improved performance. If the staff is not capable, personnel changes may have to be made for the CTA to be successful.

Time Required to Address Additional Performance Limiting Factors That May Be Found During the CTA: During the conduct of a CTA, new problems are often encountered that were not apparent during the CPE, or arise as a result of actions taken early in the CTA.

3.2.4 Facilitator Tools

Experience has shown that no single approach can address the unique combination of factors at every water treatment plant; therefore, actual details of implementation must be site-specific and should be left to the individual implementing the CTA. However, general techniques that have been successfully used in implementing CTAs are presented.

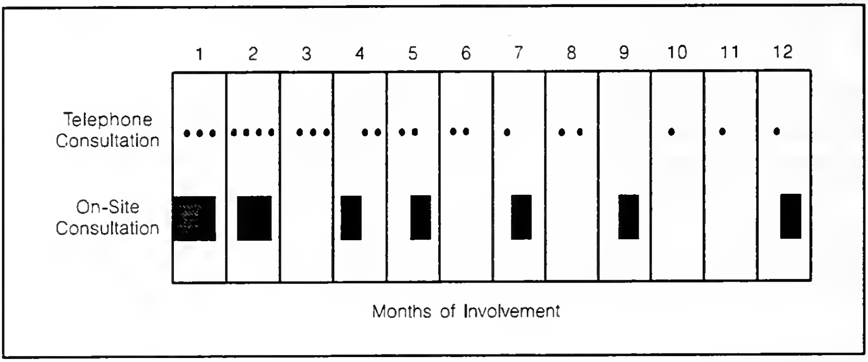
The individual who implements a CTA is called a *facilitator*. This individual is typically an "outsider" and accomplishes the objectives utilizing periods of on-site involvement (e.g. site visits) interspersed with off-site limited involvement (e.g. phone calls). This approach is graphically illustrated in Figure 3-2. The function of site visits and phone calls is further described.

Site visits are used by the facilitator to verify or clarify plant status, initiate major process control changes, test completed facility modifications, provide on-site operator or administrative training, and report progress to utility staff. Dates for site visits should be scheduled as indicated by the plant status and training requirements and not necessarily be established at specific intervals. As shown in Figure 3-2, fewer site visits and telephone calls will typically be necessary as the CTA progresses. This is in line with

the transfer of responsibility to the plant staff that occurs during the CTA. The number of site visits required by a CTA facilitator is dependent on plant size and on the specific performance limiting factors. For example, some administrative (e.g., staffing and rate changes) and design factors could significantly increase the number of site visits required to complete a CTA. Typically two to four days are spent at the plant during site visits. A final site visit is conducted to present a report.

Telephone calls are used to routinely monitor CTA progress. Routine phone contact is used to train and encourage plant personnel concerning plant observations, data interpretation, and follow-up implementation activities. Telephone calls are limited in effectiveness in that the CTA facilitator must completely rely on observations of the plant staff. To enhance communication, the CTA facilitator should always summarize important points, describe decisions that have been reached, and identify actions to be taken. Further, both the CTA facilitator and plant personnel should maintain written phone logs. Typically, two to four hours each week are spent on phone calls and data development and interpretation.

FIGURE 3-2. Typical Scheduling of CTA Activities



Specific tools have been used to increase the effectiveness of site visits and telephone calls, and to enhance the transfer of capability for achieving and maintaining desired finished water quality to plant administrators and staff. These are further described.

Contingency plans should be prepared for the occasions where a CTA is initiated at a plant that is producing unacceptable finished water quality, or where a CTA is being conducted and finished water quality deteriorates to an unacceptable level. The contingency plan should include actions such as reducing plant flow rate to improve performance, shutting down the plant, initiating public notification and initiating a boil water advisory. If plant finished water exceeds a health-based objective, the regulatory agency (Ministry of Health/Ministry of the Environment) should be immediately informed and public notification procedures mandated by the Ontario Drinking Water Objectives followed. To minimize the chance of producing unacceptable finished water while conducting a CTA, all experimentation with chemical doses and different coagulant products should be done on a bench scale (e.g. jar test) before implementing changes on a full scale basis.

Action-implementation plans should be developed and updated by the facilitator throughout the CTA to ensure progressive implementation of performance improvement activities. The "Action" plan lists items to be completed, including the name of the person that is assigned a particular task and the projected due date. The plan is normally updated and distributed to administrators and plant personnel after a site visit. Phone calls are used to encourage and monitor progress on the assigned action items. An example format for an "Action" plan is shown in Table 3-1.

TABLE 3-1. Example Action/Implementation Plan

Item	Action	Person Responsible	Due Date
1	Develop calibration curve for polymer feed pump.	Phil	12/05/96
2	Draft special study procedure to study impact on performance of reducing plant flow to 300 m^3/h.	Phil	19/05/96
3	Process Control		
	a. Develop daily process data sheet.	Jane	12/05/96
	b. Develop routine sampling plan.	Jane	19/05/96
	c. Calibrate on-line instruments.	Jane	31/05/96

Special studies can be used to evaluate and optimize unit processes, to document past performance, to modify plant process control activities, or to justify administrative or design changes necessary to improve plant performance. They are a structured, systematic approach of evaluating plant operating conditions. The format, which is shown in Table 3-2, consists of a one page write-up that defines the hypothesis, approach, duration of the study, expected results, documentation/conclusions, and implementation plan. The hypothesis should be narrow in scope and should clearly define the study which is to be conducted. The approach should provide a detailed procedure of how the study is to be conducted, including when and where samples are to be collected, who is to collect the samples, what analyses are to be conducted, and how the results are to be tabulated. This approach should be developed in conjunction with the plant staff to obtain staff commitment and to eliminate "bugs" on paper prior to beginning the study. It is important that the study results be documented using tools such as graphs, figures or tables. This allows the findings to be presented to the plant staff, administrators, regulatory officials, or other "observers" as a basis for a change in plant operation, design, maintenance or administration leading to improved plant performance. An implementation plan in conjunction with documentation addresses the procedural changes and support required to implement special study results. If all of the steps are followed, the special study approach ensures involvement by the plant staff, serves as a basis for ongoing training, and increases confidence in plant capabilities. An example special study is presented in Appendix F.

Operating procedures can be used to formalize activities that are essential to ensure consistent plant performance. Examples of procedures that can be developed include: jar testing, polymer dilution preparation, polymer and coagulant feed calculations, filter backwashing and chemical feeder calibration. Procedures are most effective if they are developed by the plant staff. Through the staff's participation, operator training is enhanced and operator familiarity with equipment manuals and operating procedures is obtained. Also, when operators are able to prepare a procedure, it indicates that they have gained a thorough understanding of the water treatment process that was discussed. The procedures should be assembled in a three-ring binder so they can be easily removed and modified as plant operating practices dictate. An example procedure is presented in Appendix G.

Process control data sheets are used to formalize the recording of results of process control testing that is initiated. Typically, a daily sheet is used to record results of tests, flow data, chemical use, etc. These data are transferred to a monthly sheet that allows observation and trending of the data. Examples of daily and monthly process control sheets are presented in Appendix H.

Graphs or trend charts can be used to enhance the interpretation of process control results. The data developed can be plotted over long periods to show seasonal trends, changes in water demand, etc. or over shorter periods to show instantaneous performance. As an example, raw, settled and filtered water turbidities were plotted over a one day period, as shown in Figure 3-3. During this period no change in coagulant dose was initiated, despite the change in raw water turbidity. As a result, settled water and finished water quality deteriorated several hours after the raw water turbidity increased. Without the use of a trend chart the correlation demonstrated would be difficult to observe.

TABLE 3-2. Example Special Study Format

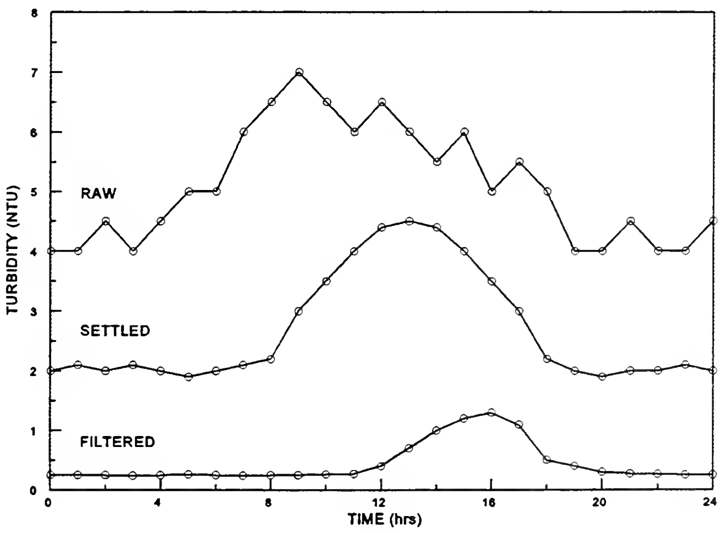
Special Study Name:	
Hypothesis:	Narrow in scope. Try to show definite cause/effect relationship.
Approach:	Detailed procedure of conducting study. Involve plant staff in development.
Duration of Study:	Important to define limits of the study since "extra work" is typically required.
Expected Results:	Projections of results focus attention on interim measurements and define success or limitations of effort.
Conclusions:	Documented impact of study allows the effort to be used as a training tool for all interested parties. Allows credit to be given for trying an approach.
Implementation:	Changes or justifies current operating procedures. Formalizes the mechanisms to improve plant performance.

A coagulant control technique must exist or be implemented during a CTA if optimized performance is to be achieved. Example coagulant control techniques include jar testing, streaming current monitors, zeta potential, and pilot filters. Jar testing is the most common technique and is discussed in more detail.

To successfully implement jar testing as a coagulant control technique requires understanding of making stock solutions and conducting the test so that it duplicates plant operating conditions as closely as possible. A typical procedure for preparing stock solutions and conducting jar tests is shown in Appendix J. Stock solutions must be prepared for any coagulant chemical (e.g., metal salts and polymers) that is going to be added to the jars.

The jar test can be set up to represent plant operating conditions by determining actual plant theoretical mixing, flocculation and sedimentation detention times; and by setting jar test mixing energy inputs, mixing times, and settling times to values similar to that in the plant. The jar test procedure should then be adjusted as necessary to obtain results similar to actual plant operation. The use of square jars is recommended because experience has shown the square jars result in more representative jar tests than round graduated cylinders since square jars break up the circular motion inherent in the cylinders.

FIGURE 3-3.Example Trend Chart Showing Relationship of Raw, Settled and Filtered Water



Chemicals should be added to duplicate plant conditions. For example, if alum is added to the plant flash mix and polymer is added to a pipeline 30 seconds downstream from the flash mix, the same sequence should be used in the jar test. The use of syringes without needles to measure and deliver the appropriate chemical dose to each jar (typically six jars are used) simplifies chemical addition.

Another essential part in the successful use of a jar test for coagulant control is the interpretation of the test results. In direct filtration plants, a small volume (about 50 mL) should be removed from the jars and passed through filter paper. Whatman #541 filter paper can be used to approximate filter performance. The filtered samples should be tested for turbidity, and the sample with the lowest turbidity generally represents the optimum chemical dose. Colour and aluminum residual measurements are also used to determine optimum dosages. For conventional plants, the jar contents should be allowed to settle for the same time as in the actual plant. Supernatant should then be drawn from a sample tap located mid-way along the side of the jar, and the turbidity (and colour) of the sample should be determined. If sample taps are not available on the jars, siphons can be used to draw-off samples from the jars. Supernatant can be filtered using Whatman 541 paper to approximate filtration. Excellent references are available to guide the facilitator in implementing jar testing to obtain optimum coagulant doses (1,2,3,4).

Letter reports are recommended to promote clarity and continuity. Since a CTA is an action-oriented program, only concise status reports are recommended. Short (one-page) written summaries should be prepared after each site visit and for each facility modification. Initially reports should be prepared by the CTA facilitator, but the responsibility should ultimately be transferred to the plant staff.

A final CTA report should be prepared to summarize activities. Since all major recommendations should have been implemented during the CTA, current status of the plant performance should be the main focus of this report.

3.2.5 Correcting Performance Limiting Factors

The major emphasis of a CTA is addressing factors identified as limiting performance. Correcting these factors provides a capable plant and allows improved process control (operation) to move the plant to continuous compliance with desired water quality objectives. Activities that can be conducted to address factors in the areas of design, administration, maintenance and operation are discussed.

3.2.5.1 Design Performance Limiting Factors

The performance of Type 2 and 3 plants may be limited by design factors that require major modifications to correct. Major modifications require the development of engineered drawings and specifications, and hiring a construction company to complete the improvements. Examples include improvements such as adding a sedimentation basin or filter. Major modifications can often be avoided by operating the plant at a lower flow rate for longer periods of time; thereby reducing the unit process hydraulic loading rate to a range that allows adequate performance to be achieved.

The performance of Type 1 and Type 2 plants can often be improved by making minor modifications or additions to the plant. A minor modification is defined as a modification that can be completed by the plant staff without development of drawings and specifications. Minor modifications include improvements such as adding a chemical feeder, developing additional chemical feed points, or installing baffles in a sedimentation basin. Examples of actual design limitations are included in Appendix I.

Ideally, the CTA facilitator and plant personnel should be able to justify each proposed plant design modification based on the resulting increased performance capability that the modification will provide. A sound basis is to relate design modifications to the need to provide a capable plant such that process

control objectives can be met (see Figure 3-1). The degree of justification required usually varies with the associated costs and specific plant circumstances. For example, little justification may be required to add a sampling tap to a filter effluent line. Whereas, justification for adding baffles to a flocculation basin would require much more emphasis. Additionally, extensive justification may be required for a facility where water rates are high and have recently been raised, yet there is no money available for an identified modification.

The CTA facilitator should transfer to the plant staff the capability to formally document the need for minor modifications. This documentation is valuable in terms of presenting a request to supervisory personnel and in providing a basis for the plant staff to continue such requests after the CTA has been completed. For many requests the special study format can be used as the approach for documenting the change (see Section 3.2.4). For modifications with a larger cost the following items may have to be added to the special study format.

- Purpose of the proposed change (e.g., how does the change relate to the development of a capable plant so that process control can be used to improve performance?).

- Detailed description of the change and an associated cost estimate.

In Ontario, modifications other than repair and maintenance items may require an amendment to the plant's Certificate of Approval, which is issued by the MOE. Temporary changes to operation for experimental purposes (e.g. alternate chemicals, alternate feed points, changing flocculator speed, changing flow splits etc.) do not require an amendment. If the operational changes become permanent, an amendment to the Certificate is required at that time. Physical modifications (e.g. construction of baffles, addition of flash mixing etc.) require an amended Certificate regardless of whether or not the modification is temporary. If there is any doubt as to whether an amendment is needed, the facilitator should recommend contacting the local MOE District Office.

Once the proposed modification has been approved by plant administrators and the MOE, the CTA facilitator should serve as a technical and managerial reference throughout the implementation of the modification. Following completion of a modification, the CTA facilitator should ensure that a formal presentation of the improved plant capability is presented to the administration. This feedback is necessary to build rapport with the plant administrators and to ensure support for future requests. The intent of the presentation should be to identify the benefits in performance obtained from the resources expended.

3.2.5.2 Maintenance Performance Limiting Factors

Maintenance can be improved in nearly all plants, but it is a significant performance limiting factor in only a small percentage of plants (5,6). The first step in addressing maintenance factors is to document any undesirable results of the current maintenance effort. If plant performance is degraded as a result of maintenance-related equipment breakdowns, the problem is easily documented. Likewise, if extensive emergency maintenance events are experienced, a need for improved preventive maintenance is easily recognized. Ideally, maintenance factors should have been previously identified and prioritized during a CPE. However, most plants do not have such obvious evidence directly correlating poor maintenance practices with poor performance; therefore, maintenance factors often do not become apparent until the conduct of the CTA.

Simply formalizing record keeping will generally improve maintenance practices to an acceptable level in many plants, particularly smaller ones. A suggested four-step procedure for developing a maintenance record keeping system is to: 1) list all equipment; 2) gather manufacturers' literature on all equipment; 3) complete equipment information summary sheets for all equipment; and 4) develop time-based preventive maintenance schedules. Equipment lists can be developed by touring the plant and by reviewing available equipment manuals. As new equipment is purchased it can be added to the list. Existing manufacturers' literature should be inventoried to identify missing but needed materials. Maintenance literature can be obtained from the manufacturer (usually a source is identified on the equipment name plate) or from local equipment representatives. Once sheets are completed for each piece of equipment, a time-based schedule can be developed. This schedule typically includes daily, weekly, monthly, quarterly, semiannual, and annual checkoff lists of required maintenance tasks.

The above system for developing a maintenance record keeping system has worked successfully at numerous plants. However, there are many other good maintenance systems, including computer-based systems. The important concept to remember is that adequate maintenance is essential to achieve consistent treated water quality.

3.2.5.3 Administrative Performance Limiting Factors

Administrators who are unfamiliar with plant needs, and thus implement policies that conflict with plant performance, are a commonly identified factor. For example, such items as implementing minor modifications, purchasing testing equipment, or expanding operator coverage may be recognized by plant operating personnel as needed performance improvement steps, but changes cannot be pursued due to lack of support by non-technical administrators. Administrative support and understanding are essential to the successful implementation of a CTA. The following techniques have proved useful in addressing identified administrative factors limiting performance:

- Build a rapport with administrators such that candid discussions concerning physical and personnel resources can take place.

- Involve plant administrators from the start. Initial visits should include time with key administrators to explain the process and possibly include a joint plant tour to increase their understanding of plant processes and problems.

- Focus administrators on their responsibility to attain a "product" that not only meets but exceeds regulatory requirements on a continuous basis. Often administrators are reluctant to pursue actions aimed at improving plant performance because of a lack of understanding of both the health implications associated with operating a water treatment plant and of their responsibilities in producing a safe finished water. Administrators must be informed that even momentary excursions in water quality must be avoided to prevent pathogenic organisms, including cysts, from passing through the treatment plant and into the distribution system. Such a breakdown in treatment could result in sickness of numerous consumers. Administrators must understand that to minimize the exposure of consumers to pathogenic organisms in their drinking water that all unit processes must be performing optimally on a continuous basis. This provides a "multiple barrier" to prevent passage of pathogenic organisms through the treatment plant. Establishment and continuous achievement of high quality treated water goals virtually guarantees that pathogenic

organisms will not reach consumers. As such, administrators should be convinced to establish goals for high quality treated water (e.g., 0.1 NTU) that exceed current objectives, and to emphasize to the operating staff the importance of achieving these goals.

- Listen carefully to the concerns of administrators so that they can be addressed. Some of their concerns or ideas may be technically unimportant, but are very important "politically." Political influence as well as technical requirements must be addressed and are considered to be an integral part of the activities of a CTA facilitator.

- Use technical data based on process needs to convince administrators to take appropriate actions; do not rely on "authority." Alternatives should be presented, when possible, and the administrators left with the decision.

- Solicit support for involvement of plant staff in the budgeting process. Budget involvement has been effective in encouraging more effective communication and in motivating plant staff.

- Encourage development of a "self-sustaining utility" attitude. This requires financial planning for modification and replacement of plant equipment and structures, which encourages communication between administrators and plant staff concerning the need to accomplish both short and long term planning. It also requires development of a fair and equitable rate structure that requires each water user (domestic, commercial, and industrial) to pay their fair share. The revenues generated should be sufficient to support long term as well as short term modification and replacement costs plus provide for ongoing items such as proper staffing, training, and chemical supplies. Reference materials are available to assist the CTA facilitator in guiding activities in this area (7,8,9).

- Encourage long term planning for future water supplies and facility improvements necessary to meet more stringent water quality requirements.

3.2.5.4 Operational Performance Limiting Factors

Improvement of plant performance is ultimately achieved by providing process control procedures, tailored for the particular plant, that can be used to move a capable facility to the desired finished water quality goal. Initial efforts should be directed toward the training of the key process control decision makers. In most plants with flows less than 2,000 m^3/d (0.45 MIGD), one person typically makes and implements all major process control decisions. In these cases, on-the-job training is usually more effective than classroom training and is recommended. If possible, in plants of this size a "back-up" person should also be trained. This "back-up" may be a junior operator or maintenance person. As the number of operators to be trained increases with plant size, the need for and effectiveness of combining classroom training with on-the-job training also increases. Since on-the-job training, or site-specific training greatly enhances the operators' capability to apply knowledge, this "hands-on" approach must be an integral part of the CTA. A discussion of process control for water treatment facilities is presented.

Process Sampling and Testing

Successful process control of a water treatment plant involves producing a consistent, high quality treated water from an often highly variable raw water surface source. To accomplish this goal, it is necessary that the performance of each unit process be optimized. This is important because a breakdown in any one unit process places a greater burden on the remaining processes and increases the chance of viable pathogenic organisms reaching the distribution system and consumer's taps. By optimizing each unit process, the benefits of providing multiple barriers prior to distribution to the consumers is realized.

To optimize each unit process, information must be routinely obtained and recorded on raw water quality and on the performance of the various unit processes in the plant so that appropriate controls can be exercised to maintain consistent treated water quality. The term routinely is stressed because it is necessary to have the plant staffed at all times it is in operation to allow information to be gathered and for process control adjustments to be made whenever water quality conditions dictate. The gathering of information in an organized and structured format involves development of a process control sampling and testing schedule.

An example process control schedule for a conventional plant is shown in Table 3-3. As shown, turbidity is one of the primary tests because it provides a quick and easily conducted measurement to determine approximate raw water quality and the effectiveness of individual plant unit processes. Raw water turbidity should be conducted on a frequent basis (e.g., every four hours) to identify changes in raw water quality. During periods of rapid change, raw water turbidity may be measured on a more frequent basis to allow adjustment of chemical dosages. Settled water turbidity should be measured a minimum of every two hours to monitor the effectiveness of the settling process and to determine if something unexpected, such as failure of an alum feeder, has occurred. Filtered water turbidity should be measured and recorded on a continuous basis to allow constant monitoring of filtered water quality. Continuous monitoring of filtered water tremendously enhances the operators' capability to properly time backwashing of filters, to determine the extent of post backwash turbidity breakthrough, and to observe if filter-regulating valve fluctuations are impacting filtered water turbidity.

The process control data should be recorded on daily sheets, and this data should be transferred to monthly sheets to allow observation of water quality trends. Appendix H includes examples of both daily and monthly process control sheets. The daily sheets should include space for recording actual chemical feed rates and the conversion of these values to a mg/L dosage so that dosage and water quality can be correlated. This database can then be used by the operator to better predict chemical feed requirements when raw water quality characteristics change suddenly. Graphs and trend charts greatly enhance these correlation efforts.

Chemical Pretreatment

The selection and control of chemical coagulants, flocculants and filter aids is the most important aspect of improving water treatment plant performance. As a rule, it is more important than the physical facilities available to treat the water. Therefore, a method to evaluate different coagulants and to control the coagulant selected is a primary focus in implementing a process control program. The special study format is especially effective for systematically optimizing chemical pretreatment.

TABLE 3-3. Example Process Control Sampling and Testing Schedule for a Small Water Treatment Plant

Sample	Location	Tests	Frequency	Sampled By
Plant Influent	Tap by raw water turbidimeter.	Turbidity	Continuous	On-line
		pH	Daily	Operator
		Alkalinity	Weekly	Operator
		Flow Rate/Total	Continuous	On-line
		Jar Test	As Needed [a]	Operator
		Temperature	Daily	Operator
Clarifier	Weir No.1 Sample Tap	Turbidity	3 Times/Day[b]	Operator
		Visual Sludge	Daily	Operator
Filter	Turbidimeter	Turbidity	Continuous	On-line
Effluent	Lab Tap	pH	Daily	Operator
		Cl_2 Residual	Continuous	On-line
		Turbidity	Every 4 Hrs.	Operator

When operating reactor clarifier in the solids contact mode (i.e., with a sludge blanket), the following additional testing is required:

Clarifier	Mixing Well	% Solids By Vol.	Daily @ Noon	Operator
	Upflow Area	Blanket Depth	3 Times/Day[b]	Operator

[a] When raw turbidity and/or pH/alkalinity change is significant
[b] Start-up, noon, shut-down

Several methods exist to determine proper coagulant dosages in conventional plants, including jar testing, zeta potential, and streaming current monitors. Jar testing is the most common procedure used. Once the correct chemical dose is determined, the staff must be able to adjust the chemical feeders to deliver the desired dosage. This requires the ability to conduct chemical calculations and to develop and utilize calibration curves for chemical feeders. For example, a mg/L dose may have to be converted to a kg/day or mL/min feed rate in order to correctly adjust a chemical feeder. Calibration curves which indicate feeder setting versus feeder output must be developed for all chemical feeders to allow the correct feeder setting for a given desired chemical dosage. Some chemicals, such as polymers, must often be prepared in dilute solutions prior to introduction into the plant flow stream. Therefore, the capability to prepare chemical dilutions must be imparted to the operators during the CTA. Example chemical feed calculations are presented in Appendix I and a procedure to develop a chemical feeder calibration curve is shown in Appendix G.

Chemical addition must not only be carefully controlled, but the correct type of coagulants, flocculants and filter aids must be applied. Typically, a metal salt and polymer should be added prior to flocculation. The metal salt should always be added to the rapid mix; however, the addition point of the cationic polymer, which may be before, after, or into the rapid mix, should be determined on a site-specific basis by conducting a special study. If alum is being utilized with a raw water pH exceeding 8.0 - 8.5, consideration should be given to switching to iron salts or polyaluminum chloride. The use of a polymer to enhance floc formation and settling can also be investigated. Investigation of filter aid polymers should be conducted since these aids are typically required if filtered water turbidities less than 0.1 NTU are to be achieved on a continuous basis. These products should be introduced into the plant flow stream at a point of gentle mixing since excessive turbulence will shear the polymer chains and make the product ineffective.

Competing chemicals should not be added at the same location. For example, the addition of lime and alum at the same point is counterproductive if the lime is raising the pH to the extent that the optimum range for alum coagulation is exceeded. The addition of powdered activated carbon at the same location as chlorine is also detrimental since the carbon will quickly adsorb the chlorine, inhibiting the ability of both chemicals. The addition of chlorine, potassium permanganate or other oxidant, in combination with some polymers, will result in the oxidation of the polymer, with a subsequent reduction in its effectiveness.

<u>Unit Process Controls</u>

<u>Mixing, Flocculation and Sedimentation</u>: The controls for mixing, flocculation and sedimentation unit processes normally include the following:

- Plant flow rate
- Type of chemical and chemical feed rate (previously discussed)
- Flocculation energy input
- Sludge removal

Plant flow rate is a primary control at many small plants that are operated for less than 24 hours each day. At these plants an excessive hydraulic loading rate on the flocculation/sedimentation processes can be avoided by operating at a lower flow rate for a longer period of time. This provides an option to meet more rigorous performance requirements with existing units without major capital improvements. The capability to reduce plant flow rate to improve performance is offset by the need to staff the plant for longer periods of time, which adds to operating costs. Therefore, plant administrators, in conjunction with the CTA facilitator, must evaluate both options.

Flocculation energy input is often fixed at small plants, either by hydraulic flocculation systems or by constant speed flocculation drives. However, flocculation energy, if low enough to allow formation of settleable floc, is not considered an essential variable to achieve desired performance of a small plant. More important are the plug flow characteristics of the flocculation system. Plug flow characteristics, similar to those found in most hydraulic flocculation systems, result in the formation of floc particles of uniform size, which greatly aids settleability. As such, greater priority may be placed on installing baffling in flocculation systems rather than trying to optimize mixing energies. Adequate time for chemical reaction is typically more important in water less than 5 °C, and this time can often be extended operationally by reducing plant flow rate.

Inadequate removal of sludge has generally not been a frequently identified factor limiting performance of sedimentation basins. To prevent a negative impact on performance, sludge need only be removed from conventional sedimentation basins frequently enough to prevent solids carryover to the filters. If it is desired to optimize sludge removal, the frequency of sludge removal can be determined by using a core sampler to monitor build-up in the basin.

Sludge control is very important in the operation of reactor type upflow sedimentation basins. The reactor section of the basin must be monitored daily and the appropriate amount of sludge removed from the basin to maintain the optimum reactor concentration and basin sludge blanket. Inadequate monitoring of the basin can lead to a loss of the sludge blanket over the weirs, which significantly impacts basin and ultimately filter performance.

Filtration: The controls for the filtration process normally include the following:

- Coagulation control;
- Filtration rate control;
- Filter aid chemical and chemical feed rate;
- Backwash frequency, duration, and rate;
- Backwash to waste.

Proper chemical pretreatment of the water prior to filtration, as discussed previously, is the key to acceptable filter performance. Improper coagulation (either underfeed or overfeed of coagulant) fails to produce particles that are large enough to be removed within the filter. Therefore, for waters that are properly chemically conditioned, flow rate is not as important a parameter. If the flow rate is constant and the water is properly conditioned, mixed media or deep bed mono-media filters can be operated at rates as high as 24 $m^3/m^2/h$ (10).

The most important aspect of flow rate relative to filter performance is the magnitude of a change in flow rate and the speed at which the change occurs (5,11). Rapid, high magnitude, flow rate increases cause a high number of particles to be washed through the filter as evidenced by significant increases in turbidity. This breakdown in filter performance, which allows previously removed particles to pass into the distribution system, disrupts the continuous performance that is required in water treatment. Since filtration is the most effective barrier to cysts such as *cryptosporidium*, even short term performance problems can potentially expose consumers to significant concentrations of cysts. These "performance failures" can occur even when the finished water turbidity objectives are being met. Filtration rate changes most often occur when a filter is removed for backwashing, high volume constant speed raw water pumps are cycled on and off, a filter is started when it is dirty, or a filter rate controller is malfunctioning.

When a filter is removed from service for washing, many plant operators leave plant flow rate the same and direct the entire plant flow to the remaining filter or filters. This places an instantaneous flow increase on the remaining filters, causing attached particles to be swept out of the filter. This can be prevented by lowering the plant flow rate prior to removing the filter from service, thereby controlling the hydraulic loading on the filters remaining in service. Starting dirty filters results in a rapid increase in flow rate and subsequent poor filtered water quality. Backwashing of filters prior to returning them to service is essential to maintain the integrity of this unit process. Rapid changes in plant influent flow by starting and stopping constant speed raw water pumps also hydraulically pushes particles through filters. This may be prevented by using a control valve (automatic or manual) to slowly adjust plant influent flow rate.

Malfunctioning filter rate control valves can result in rapid changes in filter flow rate. An ongoing preventive maintenance program is necessary to keep the valves in good working order and avoid this source of poor filter performance. If the hydraulic loading rate that the filters are expected to handle is too high, reduction of flow rate to the plant should be considered.

The utilization of a low dose of filter aid polymer can also improve filtered water quality of dual or mixed media filters. These products are very effective and can quickly blind a filter; therefore, they should be used at optimum doses (generally less than 0.1 mg/L) to avoid excessively short filter runs. These products are subject to shearing because of their long polymer chains and should be fed at points of low turbulence, such as flocculation basins or sedimentation basin effluent lines.

Filters must be backwashed at frequent enough intervals to prevent small particles from passing through the filters. Filtered water turbidity should be monitored continuously and the filter backwashed at the first indication of an increasing trend in turbidity. A general rule that can be used as a starting point when assessing the proper duration for a filter run, is that filters should be washed after filtering about 200 m^3 per m^2 of filter area per cycle. This corresponds to filter runs of 20 to 40 hours at filtration rates of 10 $m^3/m^2/h$ and 5 $m^3/m^2/h$, respectively. Very long filter runs should be avoided because they can make filters difficult to clean during backwash due to compaction of the media and can also cause an increase in biological growth on the filter.

The filter backwash duration and intensity must be great enough to clean the filter; but not so great to damage the support gravels/underdrain system or to blow media out of the filter. The length of wash should be long enough to result in clean spent backwash water because inadequate washing can result in a degradation of filter performance and the possible formation of mudballs. The filter should be probed periodically (semi-annually or annually) to inspect for support gravel problems and to check media depths. Proper cleaning can be evaluated by inspecting the filter media for mudballs and overall cleanliness, and by conducting a filter bed expansion test. A properly washed filter should have a minimum of 25 percent expansion of sand and anthracite during backwash (see p.38).

Operating procedures should be developed to describe consistent methods of backwashing filters. The procedure should include measures to prevent rapid flow rate increases to the remaining filter(s), to ensure the filter is properly cleaned, and to prevent damage to the filter by operating valves too quickly. The method of returning a filter to service should also be described because this is another time when degraded filter performance can occur. This can be minimized by optimizing coagulant and filter aid doses and by increasing the filter rate gradually when returning a recently washed filter to service. At some plants where it is still difficult to achieve high quality filtered water after the filter is placed into service, a minor modification allowing filter to waste capability may be justified. This allows directing the initial filtered water to a drain until quality improves to the extent that the water can be redirected to the clearwell.

Disinfection: The controls for the disinfection process normally include the following:

- Hydraulic flow rate (controls contact time);
- Disinfectant concentration;
- Disinfectant application point.

To provide adequate disinfection, the plant unit processes, including disinfection, should meet CT criteria

for log reduction of viruses and *Giardia* as defined in the USEPA SWTR Guidance Manual (12). The CT value, which is the residual concentration of disinfectant (mg/L) multiplied by the effective contact time (minutes) the disinfectant has had with the water prior to the first user's tap, is affected both by plant flow rate and the concentration of the disinfectant applied.

Most plants apply chlorine as a disinfectant to the filtered water prior to a clearwell. The clearwell is generally designed as a storage basin for backwash water or a wet well for finished water pumps and not as a disinfectant contactor. As a result, there are usually no baffles or other means to make the basin plug flow and the basins are typically small, which provides limited contact times. Reducing the plant flow rate or baffling the basin can often be used to gain more contact time. The maximum concentration of disinfectant that can be added because of health and aesthetic (public complaint) concerns is normally around 2.5 mg/L as free chlorine residual.

Adding a chlorine application point prior to the plant rapid mix to try to gain contact time afforded by raw water transmission lines, and flocculation and sedimentation basins can be evaluated. However, this practice, while allowing greater CT values to be obtained, may cause the excessive formation of disinfection by-products such as trihalomethanes (THMs). In addition, chlorine usage (and therefore cost) would increase because of the higher chlorine demand of raw water.

If operational changes cannot be made to achieve the specified CT values, modifications to the plant may be required to provide sufficient disinfectant contact time.

3.3 HOW TO CONDUCT A CTA

3.3.1 Initial Site Visit

A good working relationship between the CTA facilitator and the plant staff and administration should be established during the initial site visit. Such a relationship is based on mutual respect and good communication, and understanding the objective of the CTA greatly enhances the potential for success. During the initial site visit CPE results are used to prioritize follow-up activities. Ideally, activities for addressing all major performance limiting factors (rated "A" or "B" in the CPE) should be initiated.

Before implementing any major changes, the facilitator must carefully consider the potential adverse impact on plant performance and public health. Contingency plans should be prepared for the case where a CTA is initiated at a plant that is producing <u>unacceptable</u> finished water quality (see Section 3.2.4.). Actions could include plant shutdown, lowering plant flow rate, or initiating an order to boil water. In all cases contact with appropriate health officials to notify them of the problem must be accomplished. If process adjustments, such as coagulant feed, are grossly out of line, the facilitator should initiate process adjustments to minimize the adverse effect of the treated water. Jar tests or other bench scale testing should be done prior to initiating a process adjustment in order to avoid full-scale experimentation that could actually result in a further deterioration in treated water quality.

After a contingency plan has been developed to ensure protection of public health, the CTA facilitator can begin directing the implementation of process control adjustments to optimize plant performance. Changes in process control direction must be made with consideration of the operators' morale. All

recommendations for process control changes should be thoroughly explained prior to implementation. Even with this approach, a CTA facilitator should not expect to obtain immediate enthusiastic support from plant personnel. A response such as "well lets try it and see" is often the best that can be expected. Some changes may have to be made with only the degree of consensus expressed with the statement, "I don't think it will work, but we can try it."

If operations factors are top ranking, the initial site visit should be used to introduce the staff to proper process control activities, such as conducting jar tests and chemical feed calculations (see Section 3.2.4.). Existing coagulant and flocculation/filtration chemicals should be utilized in initial adjustments. Special studies can be initiated later in the CTA to determine the effectiveness or necessity of alternative chemicals.

Understanding how to determine correct chemical dosages and how to set the chemical feeders is extremely important because chemical pretreatment is normally more important in achieving optimum plant performance than physical facilities. Procedures that clearly describe these activities should be reviewed, or developed if they don't exist, during the initial visit. The plant staff then has a written description that can be consistently followed. Example procedures for calibrating a chemical feeder and calculating an alum feed rate are presented in Appendices G and J.

Existing process control testing should also be reviewed and modified so that all necessary process control elements are adequately monitored. Sampling frequency and location, collection procedures, and laboratory analyses should be reviewed and, if necessary, standardized so that data collected can be used for evaluating progress. New or modified sampling and analysis procedures should be demonstrated and documented.

Often, the necessary process control equipment is not available at the plant. Any needed sampling or testing equipment should be noted and the purchasing process should be implemented as quickly as possible. Provisions may be made for loaner equipment for essential items such as a jar tester to determine proper coagulant doses.

Data sheets, which summarize process control parameters and performance monitoring results, should be developed. Sample daily and monthly process control forms for a small plant are shown in Appendix H. It is important that a common understanding of information on the summary sheets be reached during the initial site visit since they will be used by the plant staff to provide data to the CTA facilitator throughout the CTA. The CTA facilitator reviews the data, sets operating targets and makes process control decisions in conjunction with the plant staff. Often, weekly summaries of data are used. However, if computer capability is available, electronic transfer of data can be used to allow daily data exchange.

Plant performance is often limited by the performance goals established by utility personnel. For example, many plants only try to achieve a finished water quality of 1.0 NTU because that is the Ontario objective. This attitude negatively affects the attainment of optimum unit process performance (multiple barriers) and continuous finished water quality that minimizes public exposure to pathogenic organisms. It is essential that the facilitator work with plant staff and administrators to establish aggressive treatment goals during the initial site visit and to instill in the operators and administrators the tenacity to achieve those goals. Targets for effluent turbidity that are typically established at a CTA are 1 - 2 NTU from sedimentation facilities and less than 0.1 NTU from filters.

Disinfection should be conducted to achieve the appropriate CT value described in the SWTR Guidance Manual for filtration and disinfection (12). Other treated water goals, such as taste and odor levels and reduced formation of chlorination byproducts, can also be established on a site-specific basis.

The change in attitude to support these goals often does not occur until it is demonstrated that the plant, given more intense process control, can consistently achieve a very high quality finished water. However, once this is experienced, the administrators and operators are driven by pride to maintain consistent, high quality treated water. With this pride comes the willingness of administrators to provide adequate budgets and staffing to support optimum finished water quality.

Activities to implement any minor design changes identified as necessary during the CPE and confirmed by the CTA facilitator should be initiated during the site visit. Some design changes often require significant amounts of time for approvals, delivery of equipment, or construction. It is necessary to obtain the desired capability so that it is available for implementation during the CTA.

Efforts to address administrative factors are also appropriate to be implemented during the initial site visit. Administrative changes such as increasing rates, changing personnel, or long range planning activities require significant time and diplomacy to address. The sensitivity of these issues may require that significant background information be obtained before action is taken.

3.3.2 Off-Site Activities

The CTA facilitator should provide a short letter summarizing activities during the first site visit and include a typed action-implementation plan. Any procedures or process control sheets that were developed in conjunction with the plant staff should also be formalized and returned to the utility. Typing procedures and process control sheets can help create an environment of "professionalism" concerning the CTA activities. Phone calls should be made at least weekly to obtain plant operating information and to make certain that action items are being accomplished in a satisfactory manner. A return or intermediate site visit should be made when plant operating conditions dictate or when process control equipment (e.g., jar test apparatus, filter paper, graduated cylinder, etc.) or minor design modifications that were determined necessary for future CTA activity are available for implementation efforts.

3.3.3 Follow-Up Site Visits

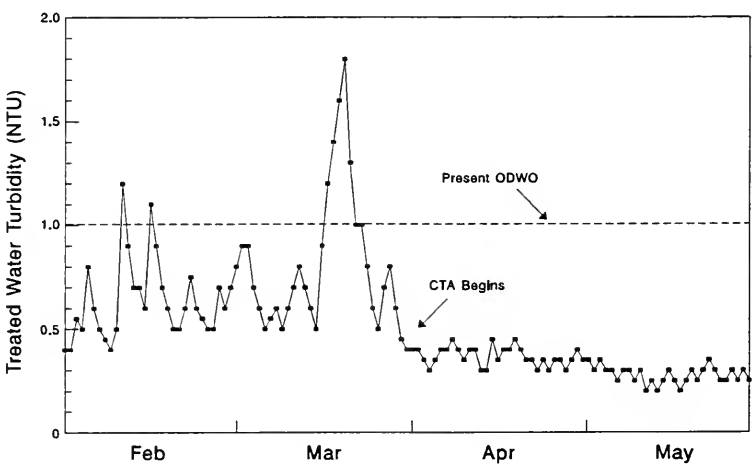
During intermediate site visits, follow-up training should be presented to the plant staff on chemical feed calculations, jar testing and other procedures initiated during the initial site visit. Repetitive training in this manner is effective in transferring capability to the operating staff. Typically, the concept of special studies (Section 3.2.4.) is also introduced at the first follow-up site visit and a prioritized list of special studies is developed in conjunction with the utility staff. During remaining site visits the facilitator should follow up on special study activities and set additional direction as required.

The facilitator should present graphs depicting performance improvement achieved during the CTA. This, coupled with additional discussion on the necessity of achieving continuous high quality water and praise regarding improved performance obtained to date, provides the operators with the incentive to continue striving to produce the highest quality water possible. During site visits, discussions must also be held with administrators to inform them of progress made and to convince them to continue support of optimum performance through adequate budgeting and staffing. During the final site visit, the results of the CTA should be presented to administrators and plant staff.

3.3.4 CTA Results

The success of conducting CTA activities can be measured by a variety of parameters, such as improved operator capability, cost savings, improved maintenance, etc. However, the true success of a CTA should be documented improved performance to the degree that the plant has achieved an optimum finished water turbidity, ideally continuously less than 0.1 NTU, but as a minimum in compliance with the ODWO. Given this objective, the results of a successful effort can be easily depicted in graphical form. Results from an actual CTA are presented in Figure 3-4. As shown, plant performance was inconsistent as depicted by the variations in finished water turbidity. However, after CTA activities had been implemented the treated water quality remained consistent at about 0.3 NTU. It is recommended that CTA results be presented in this format.

FIGURE 3-4. Example Treated Water Quality Achieved During Conduct of a CTA



3.3.5 CTA Summary Report

A CTA summary report should be prepared and presented to utility personnel upon completion of the CTA. The objective is to summarize the conclusions and document achievement of improved plant performance. The report should be brief and outline activities that were implemented to address the factors limiting plant performance. Graphs documenting the improvement in plant performance should also be presented. If other benefits were achieved these should also be documented. Eight to twelve pages are typically sufficient for the text of the report. An example CTA report is shown in Appendix K. Typical contents are:

- Introduction (reasons for the CTA);
- CPE Results (briefly summarize information from the CPE report);
- CTA Significant Events (chronological summary of activities conducted);
- CTA Results (graph of plant performance plus other CTA benefits);
- Conclusions (efforts required to maintain improved performance).

As a minimum, the CTA report should be distributed to plant administrators and key plant personnel. Further distribution of the report, for example to the design engineer or regulatory agency(ies), depends on the circumstances of the CTA, but should be done at the direction or with the awareness of local administrators.

3.3.6 Example CTA

An example CTA is difficult to present because many of the performance limiting factors are addressed through training, interpersonal relationships, weekly data review, phone consultations, and other activities conducted over a long period of time. These activities do not lend themselves readily to an abbreviated discussion. An overview of a CTA follows and is based on the example CPE presented in Section 2.4. An example of a CTA report is in Appendix K.

3.3.6.1 Addressing Performance Limiting Factors

The most serious performance limiting factors identified during the CPE were related to process control and hydraulic loading rate. Therefore, the initial portion of the CTA was directed at improving plant operations (process control) and reducing plant flow rate.

1. Operation (Process Control)

- A process control sampling and testing schedule was implemented and a daily data sheet was developed to allow evaluation and control of plant processes. On-the-job training was provided in process control testing and interpretation including the use of jar tests to determine correct coagulant doses.

- Procedures were developed for calibrating chemical feeders and calculating chemical dosages so that chemical feed rates could be accurately applied. Coagulant and filter aid doses were changed based on process control testing, which resulted in a dramatic improvement in performance.

- Weekly phone calls and transmission of plant operating data was initiated between the CTA facilitator and plant staff. Operating targets were discussed and process control changes were initiated as necessary.

- Additional process control activities required more operational attention, making it necessary to address the issue of plant coverage.

- Special studies were conducted to determine the effect of reducing plant flow rate, eliminating negative pressure from the filters, moving the alum application point and in determining the source of excessive dissolved gases in the plant influent pipeline.

2. Administration

- The improved plant performance gained through more intense process control was utilized to convince administrators to allow plant operators to be at the plant when it was in operation. The administrators' familiarity with plant needs and their ability to make appropriate decisions were increased by describing process requirements and providing them oral status reports. Administrators were also kept informed of the special studies that indicated minor modifications were necessary in the chemical feed systems.

3. Design

- Plant flow rate was decreased by 50 percent to address the poor solids capture of the upflow solids contact sedimentation basin and to address the air binding problem in the filters. A minor modification was made to the filter effluent header to allow negative pressure to be released from the bottom of the filter. These changes allowed the filters and sedimentation basins to perform in an excellent manner.

- The filter rate of flow controllers were repaired in order to eliminate rapid flow rate changes from degrading filter performance.

- A polymer feed system was installed to allow addition of a floc/filter aid. The alum feed was changed to a point just upstream from the plant control valve to increase mixing.

- Major modifications that plant administrators had planned, including construction of a presedimentation basin and moving the intake structure, were avoided.

4. Maintenance

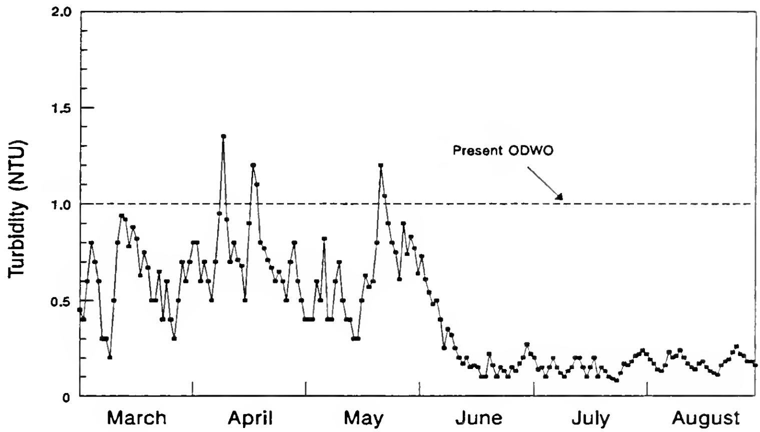
- Suggested maintenance forms were provided to the plant superintendent. However, lack of a documented preventive maintenance program had not been a significant performance limiting problem and, consequently, no additional emphasis was placed on plant maintenance.

3.3.6.2 Plant Performance

Plant performance was improved dramatically, as shown in Figure 3-5. While plant performance improved after the flow rate was reduced and the negative pressure on the filters was eliminated, performance remained erratic until process control, including chemical adjustments, was implemented. After process control was initiated in June, plant settled water and finished water turbidities remained very consistent

at about 1 to 2 NTU and 0.1 to 0.2 NTU, respectively. This consistent performance was achieved even though raw water turbidities varied widely. Another indication of improved performance was that filter effluent turbidity following a backwash did not exceed 0.3 NTU and returned to 0.15 NTU within minutes after backwash.

FIGURE 3-5. Finished Water Quality Achieved During the Example CTA



3.3.7 Discussion of the Example CTA

This example illustrates several important points of the CTA approach and includes several problems and associated solutions that occur frequently during CTA implementation. These are:

- The primary objective of a CTA is obtaining optimum plant performance. A secondary objective can be minimizing costs; however, this is often not possible if plant staff time needs to be increased or if additional treatment chemicals are needed.

- A Type 2 water treatment plant was brought into compliance with the USEPA SWTR requirements without major modifications. In fact, plans for major modifications were abandoned.

- The degree of administrative support is sometimes difficult to assess but often becomes a major concern. This was true when administrators were forced to allow operators to spend additional time at the plant for process control testing.

- Some potential performance limiting factors identified during a CPE are later found to be incorrect or less significant when actually eliminating problems with a CTA. This is especially true in evaluating the integrity of filters, which were suspect in this example, but proved to be a relatively minor problem.

3.4 REQUIRED PERSONNEL CAPABILITIES FOR CONDUCTING CTAs

Persons responsible for conducting a CTA must have a comprehensive understanding of water treatment, extensive hands-on experience in water treatment operations, and strong capabilities in personnel motivation. Comprehensive understanding of water treatment is necessary because current state-of-the-art in water treatment leaves room for individual judgment in both design and process control. For example, numerous unit processes have been used in the past and are presently being applied, such as spiral flow flocculators, plate and tube settlers, and solids contact sedimentation units. Numerous possibilities exist in terms of types, combinations and dosages of coagulant, flocculant and filter aid chemicals. Also, the types, combinations and dosages of chemical aids may vary depending on the variations in raw water supply and the unit process available at the plant to treat the water. The CTA facilitator must be familiar with all types of unit processes, raw water quality characteristics and chemical products available for successful water treatment. In addition, those responsible for implementing a CTA must have sufficient process experience to determine appropriate application of a strategy to the personnel capabilities of the plant in question. Leadership and motivational skills are required to fill the multi-faceted "facilitator" role required of individuals responsible for implementing a CTA.

Individuals who routinely work in the area of improving water treatment plant performance likely will be best qualified to be CTA facilitators. These people are typically engineers or operators who have focused their careers on water treatment plant troubleshooting and have gained experience in correcting deficiencies at plants of various types. It is important that CTA facilitators have experience in a variety of plants because the ability to recognize true causes of limited performance is a skill only developed through experience. Similarly, the successful implementation of a cost-effective CTA is greatly enhanced by experience.

By the very nature of the approach, the CTA facilitator must often address improved operation, maintenance, and minor design modifications with personnel already responsible for these water treatment functions. A "worst case situation" is one in which the plant staff is trying to prove that "the facilitator can't make it work either". The CTA facilitator must be able to deal with this personnel issue in such a manner that allows all parties involved to focus on the common goal of achieving plant performance.

A CTA facilitator must be able to conduct training in both formal and on-the-job situations. Training capabilities must also be developed so they are effective with both operating as well as administrative personnel. When addressing process control limitations, training must be geared to the specific capabilities of the process control decision makers. Some may be inexperienced; others may have considerable experience and credentials. "Administrative" training is often a matter of clearly providing information to justify or support CTA activities. Although many administrators are competent, some may not know what their facilities require in terms of staffing, minor modifications, or specific funding needs.

CTA facilitators include consultants, regulatory personnel, or utility employees. However, the desired "existing facility" focus of a facilitator must be maintained, since a substantial construction cost can be incurred if an inexperienced facilitator is not able to bring a capable water treatment plant to the desired level of performance. For example, a consultant, involved primarily with facility design, may not have the operational experience to utilize the capability of existing unit processes to their fullest extent and may be biased toward designing and constructing new facilities.

If utilities/municipalities decide to conduct a CTA with people closely associated with the plant, they should recognize that some inherent problems may exist. The individuals implementing the CTA, for example, often find it difficult to provide an unbiased assessment of the area in which they normally work. Operating personnel tend to look at design and administration as problem areas while administrators typically feel that operating personnel should be able to do better with what they have. In addition, the engineer who approved a facility's design is often reluctant to admit design limitations. These biases should be considered before personnel closely associated with the plant initiate a CTA.

3.5 REFERENCES

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APPENDIX A

CT Values for Inactivation of Giardia and Viruses

Table A-1. CT Values for Inactivation of *Giardia* Cysts by Free Chlorine at 0.5°C or Lower[1]

Chlorine Conc. (mg/L)	pH≤6.0 Logs Inactivation						pH=6.5 Logs Inactivation						pH=7.0 Logs Inactivation						pH=7.5 Logs Inactivation					
	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0
≤0.4	23	46	69	91	114	137	27	54	82	109	136	163	33	65	98	130	163	195	40	79	119	158	198	237
0.6	24	47	71	94	118	141	28	56	84	112	140	168	33	67	100	133	167	200	40	80	120	159	199	239
0.8	24	48	73	97	121	145	29	57	86	115	143	172	34	68	103	137	171	205	41	82	123	164	205	246
1	25	49	74	99	123	148	29	59	88	117	147	176	35	70	105	140	175	210	42	84	127	169	211	253
1.2	25	51	76	101	127	152	30	60	90	120	150	180	36	72	108	143	179	215	43	86	130	173	216	259
1.4	26	52	78	103	129	155	31	61	92	123	153	184	37	74	111	147	184	221	44	89	133	177	222	266
1.6	26	52	79	105	131	157	32	63	95	126	158	189	38	75	113	151	188	226	46	91	137	182	228	273
1.8	27	54	81	108	135	162	32	64	97	129	161	193	39	77	116	154	193	231	47	93	140	186	233	279
2	28	55	83	110	138	165	33	66	99	131	164	197	39	79	118	157	197	236	48	95	143	191	238	286
2.2	28	56	85	113	141	169	34	67	101	134	168	201	40	81	121	161	202	242	50	99	149	198	248	297
2.4	29	57	86	115	143	172	34	68	103	137	171	205	41	82	124	165	206	247	50	99	149	199	248	298
2.6	29	58	88	117	146	175	35	70	105	139	174	209	42	84	126	168	210	252	51	101	152	203	253	304
2.8	30	59	89	119	148	178	36	71	107	142	178	213	43	86	129	171	214	257	52	103	155	207	258	310
3	30	60	91	121	151	181	36	72	109	145	181	217	44	87	131	174	218	261	53	105	158	211	263	316

Chlorine Conc. (mg/L)	pH=8.0 Logs Inactivation						pH=8.5 Logs Inactivation						pH≤9.0 Logs Inactivation					
	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0
≤0.4	46	92	139	185	231	277	55	110	165	219	274	329	65	130	195	260	325	390
0.6	48	95	143	191	238	286	57	114	171	228	285	342	68	136	204	271	339	407
0.8	49	98	148	197	246	295	59	118	177	236	295	354	70	141	211	281	352	422
1	51	101	152	203	253	304	61	122	183	243	304	365	73	146	219	291	364	437
1.2	52	104	157	209	261	313	63	125	188	251	313	376	75	150	226	301	376	451
1.4	54	107	161	214	268	321	65	129	194	258	323	387	77	155	232	309	387	464
1.6	55	110	165	219	274	329	66	132	199	265	331	397	80	159	239	318	398	477
1.8	56	113	169	225	282	338	68	136	204	271	339	407	82	163	245	326	408	489
2	58	115	173	231	288	346	70	139	209	278	348	417	83	167	250	333	417	500
2.2	59	118	177	235	294	353	71	142	213	284	355	426	86	170	256	341	426	511
2.4	60	120	181	241	301	361	73	145	218	290	363	435	87	174	261	348	435	522
2.6	61	123	184	245	307	368	74	148	222	296	370	444	89	178	267	355	444	533
2.8	63	125	188	250	313	375	75	151	226	301	377	452	91	181	272	362	453	543
3	64	127	191	255	318	382	77	153	230	307	383	460	92	184	276	368	460	552

Table A-2. CT Values for Inactivation of *Giardia* Cysts by Free Chlorine at 5°C[1]

Chlorine Conc. (mg/L)	pH≤6.0 Logs inactivation						pH=6.5 Logs inactivation						pH=7.0 Logs inactivation						pH=7.5 Logs inactivation					
	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0
≤0.4	16	32	49	65	81	97	20	39	59	78	98	117	23	46	70	93	116	139	28	55	83	111	138	166
0.6	17	33	50	67	83	100	20	40	60	80	100	120	24	48	72	95	119	143	29	57	86	114	143	171
0.8	17	34	52	69	86	103	20	41	61	81	102	122	24	49	73	97	122	146	29	58	88	117	146	175
1	18	35	53	70	88	105	21	42	63	83	104	125	25	50	75	99	124	149	30	60	90	119	149	179
1.2	18	36	54	71	89	107	21	42	64	85	106	127	25	51	76	101	127	152	31	61	92	122	153	183
1.4	18	36	55	73	91	109	22	43	65	87	108	130	26	52	78	103	129	155	31	62	94	125	156	187
1.6	19	37	56	74	93	111	22	44	66	88	110	132	26	53	79	105	132	158	32	64	96	128	160	192
1.8	19	38	57	76	95	114	23	45	68	90	113	135	27	54	81	108	135	162	33	65	98	131	163	196
2	19	38	58	77	97	116	23	46	69	92	115	138	28	55	83	110	138	165	33	67	100	133	167	200
2.2	20	39	59	79	98	118	23	47	70	93	117	140	28	56	85	113	141	169	34	68	102	136	170	204
2.4	20	40	60	80	100	120	24	48	72	95	119	143	29	57	86	115	143	172	35	70	105	139	174	209
2.6	20	41	61	81	102	122	24	49	73	97	122	146	29	58	88	117	146	175	36	71	107	142	178	213
2.8	21	41	62	83	103	124	25	49	74	99	123	148	30	59	89	119	148	178	36	72	109	145	181	217
3	21	42	63	84	105	126	25	50	76	101	126	151	30	61	91	121	152	182	37	74	111	147	184	221

Chlorine Conc. (mg/L)	pH=8.0 Logs inactivation						pH=8.5 Logs inactivation						pH≤9.0 Logs inactivation					
	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0
≤0.4	33	66	99	132	165	198	39	79	118	157	197	236	47	93	140	186	233	279
0.6	34	68	102	136	170	204	41	81	122	163	203	244	49	97	146	194	243	291
0.8	35	70	105	140	175	210	42	84	126	168	210	252	50	100	151	201	251	301
1	36	72	108	144	180	216	43	87	130	173	217	260	52	104	156	208	260	312
1.2	37	74	111	147	184	221	45	89	134	178	223	267	53	107	160	213	267	320
1.4	38	76	114	151	189	227	46	91	137	183	228	274	55	110	165	219	274	329
1.6	39	77	116	155	193	232	47	94	141	187	234	281	56	112	169	225	281	337
1.8	40	79	119	159	198	238	48	96	144	191	239	287	58	115	173	230	288	345
2	41	81	122	162	203	243	49	98	147	196	245	294	59	118	177	235	294	353
2.2	41	83	124	165	207	248	50	100	150	200	250	300	60	120	181	241	301	361
2.4	42	84	127	169	211	253	51	102	153	204	255	306	61	123	184	245	307	368
2.6	43	86	129	172	215	258	52	104	156	208	260	312	63	125	188	250	313	375
2.8	44	88	132	175	219	263	53	106	159	212	265	318	64	127	191	255	318	382
3	45	89	134	179	223	268	54	108	162	216	270	324	65	130	195	259	324	389

Table A-3. CT Values for Inactivation of *Giardia* Cysts by Free Chlorine at 10°C[1]

Chlorine Conc. (mg/L)	pH≤6.0 Logs Inactivation						pH=6.5 Logs Inactivation						pH=7.0 Logs Inactivation						pH=7.5 Logs Inactivation					
	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0
≤0.4	12	24	37	49	61	73	15	29	44	59	73	88	17	35	52	69	87	104	21	42	63	83	104	125
0.6	13	25	38	50	63	75	15	30	45	60	75	90	18	36	54	71	89	107	21	43	64	85	107	128
0.8	13	26	39	52	65	78	15	31	46	61	77	92	18	37	55	73	92	110	22	44	66	87	109	131
1	13	26	40	53	66	79	16	31	47	63	78	94	19	37	56	75	93	112	22	45	67	89	112	134
1.2	13	27	40	53	67	80	16	32	48	63	79	95	19	38	57	76	95	114	23	46	69	91	114	137
1.4	14	27	41	55	68	82	16	33	49	65	82	98	19	39	58	77	97	116	23	47	70	93	117	140
1.6	14	28	42	55	69	83	17	33	50	66	83	99	20	40	60	79	99	119	24	48	72	96	120	144
1.8	14	29	43	57	72	86	17	34	51	67	84	101	20	41	61	81	102	122	25	49	74	98	123	147
2	15	29	44	58	73	87	17	35	52	69	87	104	21	41	62	83	103	124	25	50	75	100	125	150
2.2	15	30	45	59	74	89	18	35	53	70	88	105	21	42	64	85	106	127	26	51	77	102	128	153
2.4	15	30	45	60	75	90	18	36	54	71	89	107	22	43	65	86	108	129	26	52	79	105	131	157
2.6	15	31	46	61	77	92	18	37	55	73	92	110	22	44	66	87	109	131	27	53	80	107	133	160
2.8	16	31	47	62	78	93	19	37	56	74	93	111	22	45	67	89	112	134	27	54	82	109	136	163
3	16	32	48	63	79	95	19	38	57	75	94	113	23	46	69	91	114	137	28	55	83	111	138	166

Chlorine Conc. (mg/L)	pH=8.0 Logs Inactivation						pH=8.5 Logs Inactivation						pH≤9.0 Logs Inactivation					
	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0
≤0.4	25	50	75	99	124	149	30	59	89	118	148	177	35	70	105	139	174	209
0.6	26	51	77	102	128	153	31	61	92	122	153	183	36	73	109	145	182	218
0.8	26	53	79	105	132	158	32	63	95	126	158	189	38	75	113	151	188	226
1	27	54	81	108	135	162	33	65	98	130	163	195	39	78	117	156	195	234
1.2	28	55	83	111	138	166	33	67	100	133	167	200	40	80	120	160	200	240
1.4	28	57	85	113	142	170	34	69	103	137	172	206	41	82	124	165	206	247
1.6	29	58	87	116	145	174	35	70	106	141	176	211	42	84	127	169	211	253
1.8	30	60	90	119	149	179	36	72	108	143	179	215	43	86	130	173	216	259
2	30	61	91	121	152	182	37	74	111	147	184	221	44	88	133	177	221	265
2.2	31	62	93	124	155	186	38	75	113	150	188	225	45	90	136	181	226	271
2.4	32	63	95	127	158	190	38	77	115	153	192	230	46	92	138	184	230	276
2.6	32	65	97	129	162	194	39	78	117	156	195	234	47	94	141	187	234	281
2.8	33	66	99	131	164	197	40	80	120	159	199	239	48	96	144	191	239	287
3	34	67	101	134	168	201	41	81	122	162	203	243	49	97	146	195	243	292

Table A-4. CT Values for Inactivation of *Giardia* Cysts by Free Chlorine at 15°C[1]

Chlorine Conc. (mg/L)	pH≤6.0 Logs Inactivation						pH=6.5 Logs Inactivation						pH=7.0 Logs Inactivation						pH=7.5 Logs Inactivation					
	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0
≤0.4	8	16	25	33	41	49	10	20	30	39	49	59	12	23	35	47	58	70	14	28	42	55	69	83
0.6	8	17	25	33	42	50	10	20	30	40	50	60	12	24	36	48	60	72	14	29	43	57	72	86
0.8	9	17	26	35	43	52	10	20	31	41	51	61	12	24	37	49	61	73	15	29	44	59	73	88
1	9	18	27	35	44	53	11	21	32	42	53	63	13	25	38	50	63	75	15	30	45	60	75	90
1.2	9	18	27	36	45	54	11	21	32	43	53	64	13	25	38	51	63	76	15	31	46	61	77	92
1.4	9	18	28	37	46	55	11	22	33	43	54	65	13	26	39	52	65	78	16	31	47	63	78	94
1.6	9	19	28	37	47	56	11	22	33	44	55	66	13	26	40	53	66	79	16	32	48	64	80	96
1.8	10	19	29	38	48	57	11	23	34	45	57	68	14	27	41	54	68	81	16	33	49	65	82	98
2	10	19	29	39	48	58	12	23	35	46	58	69	14	28	42	55	69	83	17	33	50	67	83	100
2.2	10	20	30	39	49	59	12	23	35	47	58	70	14	28	43	57	71	85	17	34	51	68	85	102
2.4	10	20	30	40	50	60	12	24	36	48	60	72	14	29	43	57	72	86	18	35	53	70	88	105
2.6	10	20	31	41	51	61	12	24	37	49	61	73	15	29	44	59	73	88	18	36	54	71	89	107
2.8	10	21	31	41	52	62	12	25	37	49	62	74	15	30	45	59	74	89	18	36	55	73	91	109
3	11	21	32	42	53	63	13	25	38	51	63	76	15	30	46	61	76	91	19	37	56	74	93	111

Chlorine Conc. (mg/L)	pH=8.0 Logs Inactivation						pH=8.5 Logs Inactivation						pH≤9.0 Logs Inactivation					
	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0
≤0.4	17	33	50	68	83	99	20	39	59	79	98	118	23	47	70	93	117	140
0.6	17	34	51	68	85	102	20	41	61	81	102	122	24	49	73	97	122	146
0.8	18	35	53	70	88	105	21	42	63	84	105	126	25	50	76	101	126	151
1	18	36	54	72	90	108	22	43	65	87	108	130	26	52	78	104	130	156
1.2	19	37	56	74	93	111	22	45	67	89	112	134	27	53	80	107	133	160
1.4	19	38	57	76	95	114	23	46	69	91	114	137	28	55	83	110	138	165
1.6	19	39	58	77	97	116	24	47	71	94	118	141	28	56	85	113	141	169
1.8	20	40	60	79	99	119	24	48	72	96	120	144	29	58	87	115	144	173
2	20	41	61	81	102	122	25	49	74	98	123	147	30	59	89	118	148	177
2.2	21	41	62	83	103	124	25	50	75	100	125	150	30	60	91	121	151	181
2.4	21	42	64	85	106	127	26	51	77	102	128	153	31	61	92	123	153	184
2.6	22	43	65	86	108	129	26	52	78	104	130	156	31	63	94	125	157	188
2.8	22	44	66	88	110	132	27	53	80	106	133	159	32	64	96	127	159	191
3	22	45	67	89	112	134	27	54	81	108	135	162	33	65	98	130	163	195

Table A-5. CT Values for Inactivation of *Giardia* Cysts by Free Chlorine at 20°C[1]

Chlorine Conc. (mg/L)	pH≤6.0 Logs Inactivation						pH=6.5 Logs Inactivation						pH=7.0 Logs Inactivation						pH=7.5 Logs Inactivation					
	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0
≤0.4	6	12	18	24	30	36	7	15	22	29	37	44	9	17	26	35	43	52	10	21	31	41	53	62
0.6	6	13	19	25	32	38	8	15	23	30	38	45	9	18	27	36	45	54	11	21	32	43	53	64
0.8	7	13	20	26	33	39	8	15	23	31	38	46	9	18	28	37	46	55	11	22	33	44	55	66
1	7	13	20	26	33	39	8	16	24	31	39	47	9	19	28	37	47	56	11	22	34	45	56	67
1.2	7	13	20	27	33	40	8	16	24	32	40	48	10	19	29	38	48	57	12	23	35	46	58	69
1.4	7	14	21	27	34	41	8	16	25	33	41	49	10	19	29	39	48	58	12	23	35	47	58	70
1.6	7	14	21	28	35	42	8	17	25	33	42	50	10	20	30	39	49	59	12	24	36	48	60	72
1.8	7	14	22	29	36	43	9	17	26	34	43	51	10	20	31	41	51	61	12	25	37	49	62	74
2	7	15	22	29	36	44	9	17	26	35	43	52	10	21	31	41	52	62	13	25	38	50	63	75
2.2	7	15	22	29	37	44	9	18	27	35	44	53	11	21	32	42	53	63	13	26	39	51	64	77
2.4	8	15	23	30	38	45	9	18	27	36	45	54	11	22	33	43	54	65	13	26	39	52	65	78
2.6	8	15	23	31	38	46	9	18	28	37	46	55	11	22	33	44	55	66	13	27	40	53	67	80
2.8	8	16	24	31	39	47	9	19	28	37	47	56	11	22	34	45	56	67	14	27	41	54	68	81
3	8	16	24	31	39	47	10	19	29	38	48	57	11	23	34	45	57	68	14	28	42	55	69	83

Chlorine Conc. (mg/L)	pH=8.0 Logs Inactivation						pH=8.5 Logs Inactivation						pH≤9.0 Logs Inactivation					
	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0
≤0.4	12	25	37	49	62	74	15	30	45	59	74	89	18	35	53	70	88	105
0.6	13	26	39	51	64	77	15	31	46	61	77	92	18	36	55	73	91	109
0.8	13	26	40	53	66	79	16	32	48	63	79	95	19	38	57	75	94	113
1	14	27	41	54	68	81	16	33	49	65	82	98	20	39	59	78	98	117
1.2	14	28	42	55	69	83	17	33	50	67	83	100	20	40	60	80	100	120
1.4	14	28	43	57	71	85	17	34	52	69	86	103	21	41	62	82	103	123
1.6	15	29	44	58	73	87	18	35	53	70	88	105	21	42	63	84	105	126
1.8	15	30	45	59	74	89	18	36	54	72	90	108	22	43	65	86	108	129
2	15	30	46	61	76	91	18	37	55	73	92	110	22	44	66	88	110	132
2.2	16	31	47	62	78	93	19	38	57	75	94	113	23	45	68	90	113	135
2.4	16	32	48	63	79	95	19	38	58	77	96	115	23	46	69	92	115	138
2.6	16	32	49	65	81	97	20	39	59	78	98	117	24	47	71	94	118	141
2.8	17	33	50	66	83	99	20	40	60	79	99	119	24	48	72	95	119	143
3	17	34	51	67	84	101	20	41	61	81	102	122	24	49	73	97	122	146

Table A-6. CT Values for Inactivation of *Giardia* Cysts by Free Chlorine at 25°C[1]

Chlorine Conc. (mg/L)	pH≤6.0 Logs Inactivation						pH=6.5 Logs Inactivation						pH=7.0 Logs Inactivation						pH=7.5 Logs Inactivation					
	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0
≤0.4	4	8	12	16	20	24	5	10	15	19	24	29	6	12	18	23	29	35	7	14	21	28	35	42
0.6	4	8	13	17	21	25	5	10	15	20	25	30	6	12	18	24	30	36	7	14	22	29	36	43
0.8	4	9	13	17	22	26	5	10	16	21	26	31	6	12	19	25	31	37	7	15	22	29	37	44
1	4	9	13	17	22	26	5	10	16	21	26	31	6	12	19	25	31	37	8	15	23	30	38	45
1.2	5	9	14	18	23	27	5	11	16	21	27	32	6	13	19	25	32	38	8	15	23	31	38	46
1.4	5	9	14	18	23	27	6	11	17	22	28	33	7	13	20	26	33	39	8	16	24	31	39	47
1.6	5	9	14	19	23	28	6	11	17	22	28	33	7	13	20	27	33	40	8	16	24	32	40	48
1.8	5	10	15	19	24	29	6	11	17	23	28	34	7	14	21	27	34	41	8	16	25	33	41	49
2	5	10	15	19	24	29	6	12	18	23	29	35	7	14	21	27	34	41	8	17	25	33	42	50
2.2	5	10	15	20	25	30	6	12	18	23	29	35	7	14	21	28	35	42	9	17	26	34	43	51
2.4	5	10	15	20	25	30	6	12	18	24	30	36	7	14	22	29	36	43	9	17	26	35	43	52
2.6	5	10	16	21	26	31	6	12	19	25	31	37	7	15	22	29	37	44	9	18	27	35	44	53
2.8	5	10	16	21	26	31	6	12	19	25	31	37	8	15	23	30	38	45	9	18	27	36	45	54
3	5	11	16	21	27	32	6	13	19	25	32	38	8	15	23	31	38	46	9	18	28	37	46	55

Chlorine Conc. (mg/L)	pH=8.0 Logs Inactivation						pH=8.5 Logs Inactivation						pH≤9.0 Logs Inactivation					
	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0
≤0.4	8	17	25	33	42	50	10	20	30	39	49	59	12	23	35	47	58	70
0.6	9	17	26	34	43	51	10	20	31	41	51	61	12	24	37	49	61	73
0.8	9	18	27	35	44	53	11	21	32	42	53	63	13	25	38	50	63	75
1	9	18	27	36	45	54	11	22	33	43	54	65	13	26	39	52	65	78
1.2	9	18	28	37	46	55	11	22	34	45	56	67	13	27	40	53	67	80
1.4	10	19	29	38	48	57	12	23	35	46	58	69	14	27	41	55	68	82
1.6	10	19	29	39	48	58	12	23	35	47	58	70	14	28	42	56	70	84
1.8	10	20	30	40	50	60	12	24	36	48	60	72	14	29	43	57	72	86
2	10	20	31	41	51	61	12	25	37	49	62	74	15	29	44	59	73	88
2.2	10	21	31	41	52	62	13	25	38	50	63	75	15	30	45	60	75	90
2.4	11	21	32	42	53	63	13	26	39	51	64	77	15	31	46	61	77	92
2.6	11	22	33	43	54	65	13	26	39	52	65	78	16	31	47	63	78	94
2.8	11	22	33	44	55	66	13	27	40	53	67	80	16	32	48	64	80	96
3	11	22	34	45	56	67	14	27	41	54	68	81	16	32	49	65	81	97

Table A-7. CT Values for Inactivation of Viruses by Free Chlorine[1]

Temperature (°C)	Logs Inactivation					
	2.0		3.0		4.0	
	pH 6-9	pH 10	pH 6-9	pH 10	pH 6-9	pH 10
0.5	6	45	9	66	12	90
5	4	30	6	44	8	60
10	3	22	4	33	6	45
15	2	15	3	22	4	30
20	1	11	2	16	3	22
25	1	7	1	11	2	15

Table A-8. CT Values for Inactivation of *Giardia* Cysts by Chlorine Dioxide[1]

Logs Inactivation	Temperature (°C)					
	≤1	5	10	15	20	25
0.5	10	4.3	4	3.2	2.5	2
1	21	8.7	7.7	6.3	5	3.7
1.5	32	13	12	10	7.5	5.5
2	42	17	15	13	10	7.3
2.5	52	22	19	16	13	9
3	63	26	23	19	15	11

Table A-9. CT Values for Inactivation of Viruses by Chlorine Dioxide at pH 6-9[1]

Logs Inactivation	Temperature (°C)					
	≤1	5	10	15	20	25
2	8.4	5.6	4.2	2.8	2.1	1.4
3	25.6	17.1	12.8	8.6	6.4	4.3
4	50.1	33.4	25.1	16.7	12.5	8.4

Table A-10. CT Values for Inactivation of *Giardia* Cysts by Ozone[1]

Logs Inactivation	Temperature (°C)					
	≤1	5	10	15	20	25
0.5	0.48	0.32	0.23	0.16	0.1	0.08
1	0.97	0.63	0.48	0.32	0.2	0.16
1.5	1.5	0.95	0.72	0.48	0.36	0.24
2	1.9	1.3	0.95	0.63	0.48	0.32
2.5	2.4	1.6	1.2	0.79	0.60	0.40
3	2.9	1.9	1.43	0.95	0.72	0.48

Table A-11. CT Values for Inactivation of Viruses by Ozone[1]

Logs Inactivation	Temperature (°C)					
	≤1	5	10	15	20	25
2	0.9	0.6	0.5	0.3	0.25	0.15
3	1.4	0.9	0.8	0.5	0.4	0.25
4	1.8	1.2	1.0	0.6	0.5	0.3

Table A-12. CT Values for Inactivation of *Giardia* Cysts by Chloramine at pH 6-9[1]

Logs Inactivation	Temperature (°C)					
	≤1	5	10	15	20	25
0.5	635	365	310	250	185	125
1	1,270	735	615	500	370	250
1.5	1,900	1,100	930	750	550	375
2	2,535	1,470	1,230	1,000	735	500
2.5	3,170	1,830	1,540	1,250	915	625
3	3,800	2,200	1,850	1,500	1,100	750

Table A-13. CT Values for Inactivation of Viruses by Chloramine[1]

Logs Inactivation	Temperature (°C)					
	≤1	5	10	15	20	25
2	1,243	857	643	428	321	214
3	2,068	1,423	1,067	712	534	356
4	2,883	1,988	1,491	994	746	497

[1] All tables in this appendix are taken from the "Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems Using Surface Water Sources - Appendix E", Office of Drinking Water, U.S. EPA, Washington DC, October 1990.

APPENDIX B

Classification System, Factor Checklist, and Definitions for Assessing Performance-Limiting Factors

CPE SUMMARY SHEET TERMS

PLANT TYPE	Brief but specific description of type of plant (e.g., conventional with flash mix, flocculation, sedimentation, filtration and chlorine disinfection or direct filtration with flash mix, flocculation and disinfection).
RAW WATER SOURCE	Brief description of water source (e.g., surface water including name of river or ground water including geologic formation).
PLANT PERFORMANCE SUMMARY	Brief description of plant performance as related to desired water quality.
RANKING TABLE	A list of the major causes of decreased plant performance and reliability.
RANKING	Causes of decreased plant performance and reliability, with the most critical ones listed first (typically only "A" and "B" factors are listed).
TYPE A OR B	Identify factors as to A (major effect on a long term repetitive basis) or B (minimum effect on a routine basis or major effect on a periodic basis).
PERFORMANCE LIMITING FACTORS AND CATEGORY	Items identified from the Checklist of Performance Limiting Factors. Identify factor category (e.g., administration, design, operations, or maintenance).

CPE SUMMARY SHEET FOR RANKING PERFORMANCE LIMITING FACTORS

Plant Name/Location ____________________

CPE Performed By ____________________ Date ____________

Plant Type ____________________

Raw Water Source ____________________

Plant Performance Summary:

RANKING TABLE

RANKING	TYPE A or B	PERFORMANCE LIMITING FACTOR/CATEGORY
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		

A - Major effect on a long term repetitive basis.
B - Minimum effect on a routine basis or major effect on a periodic basis.
C - Minor effect.

CPE CLASSIFICATION SYSTEM, FACTORS CHECKLIST, AND DEFINITIONS FOR ASSESSING PERFORMANCE LIMITING FACTORS

CLASSIFICATION SYSTEM FOR PRIORITIZING PERFORMANCE LIMITING FACTORS*

<u>Rating</u>	<u>Adverse Effect of Factor on Plant Performance</u>
A	Major effect on a long term repetitive basis.
B	Minimum effect on a routine basis or major effect on a periodic basis.
C	Minor effect.
NR	No Rating - factor has no adverse effect on plant performance (i.e., satisfactory assessment of this potentially performance limiting item).

* Factors are assessed based on their adverse effect on achieving desired finished water quality.

CHECKLIST OF PERFORMANCE LIMITING FACTORS

FACTOR	RATING	COMMENTS
A. Administration		
1. Plant Administrators		
a. Policies	______	______
b. Familiarity With Plant Needs	______	______
c. Supervision	______	______
d. Planning	______	______
2. Plant Staff		
a. Manpower		
1) Number	______	______
2) Plant Coverage	______	______
3) Workload Distribution	______	______
4) Personnel Turnover	______	______
b. Morale		
1) Motivation	______	______
2) Pay	______	______
3) Work Environment	______	______
c. Staff Qualifications		
1) Aptitude	______	______
2) Level of Education	______	______
3) Certification	______	______
d. Productivity	______	______
3. Financial		
a. Insufficient Funding	______	______
b. Unnecessary Spending	______	______
c. Indebtedness	______	______
4. Water Demand	______	______
B. Maintenance		
1. Preventive		
a. Lack of Program	______	______
b. Spare Parts Inventory	______	______
2. Corrective		
a. Procedures	______	______

CHECKLIST OF PERFORMANCE LIMITING FACTORS (cont.)

FACTOR	RATING	COMMENTS
B. Maintenance (cont.)		
b. Critical Parts Procurement	______	______
3. General		
a. Housekeeping	______	______
b. References Available	______	______
c. Staff Expertise	______	______
d. Technical Guidance	______	______
e. Equipment Age	______	______
C. Design		
1. Raw Water		
a. THM Precursors	______	______
b. Turbidity	______	______
c. Seasonal Variation	______	______
d. Watershed Mgmnt.	______	______
2. Unit Design Adequacy		
a. Pretreatment		
1) Intake Structure	______	______
2) Presedimentation	______	______
3) Prechlorination	______	______
b. Low Lift Pumping	______	______
c. Flash Mix	______	______
d. Flocculation	______	______
e. Sedimentation	______	______
f. Filtration	______	______
g. Disinfection	______	______
h. Sludge Treatment	______	______
i. Ultimate Sludge/Back-Wash Water Disposal	______	______
j. Fluoridation	______	______
3. Miscellaneous		
a. Process Flexibility	______	______
b. Process Controllability	______	______
c. Process Automation	______	______

CHECKLIST OF PERFORMANCE LIMITING FACTORS (cont.)

FACTOR	RATING	COMMENTS
C. DESIGN (cont.)		
d. Lack of Standby Units For Key Equipment	______	______________________
e. Flow Proportioning to Unit Processes	______	______________________
f. Alarm Systems	______	______________________
g. Alternate Power Source	______	______________________
h. Lab Space/ Equipment	______	______________________
i. Sample Taps	______	______________________
j. Plant Inoperability Due To Weather	______	______________________
k. Return Process Stream	______	______________________
D. Operation		
1. Testing		
a. Performance Monitoring	______	______________________
b. Process Control Testing	______	______________________
2. Process Control Adjustments		
a. Water Treatment Understanding	______	______________________
b. Application of Concepts and Testing to Process Control	______	______________________
c. Technical Guidance	______	______________________
d. Training	______	______________________
e. Insufficient Time on Job	______	______________________
3. O&M Manual/Procedure		
a. Adequacy	______	______________________
b. Use	______	______________________
4. Distribution System	______	______________________
E. Miscellaneous		
1.	______	______________________
2.	______	______________________

DEFINITIONS OF PERFORMANCE LIMITING FACTORS

A. ADMINISTRATION

1. Plant Administrators

a.	Policies	Do operating staff members have authority to make required operation (e.g., adjust chemical feed), maintenance (e.g., hire electrician), and/or administrative (e.g., purchase critical piece of equipment) decisions, or do policies cause critical decisions to be delayed which in turn affect plant performance and reliability? Does any established administrative policy limit plant performance (e.g., non-support of training; or plant funding too low because of emphasis to avoid rate increases)?
b.	Familiarity With Plant Needs	Do administrators have a first-hand knowledge of plant needs through plant visits or discussions with operators? If not, has this been a cause of poor plant performance and reliability through poor budget decisions, poor staff morale, or limited support for plant modifications?
c.	Supervision	Do management styles, organizational capabilities, budgeting skills, or communication practices at any management level adversely impact the plant to the extent that performance is affected?
d.	Planning	Does lack of long range plans for facility replacement, alternative source waters, emergency response, etc. adversely impact the plant performance?

2. Plant Staff

a. Manpower

1)	Number	Does a limited number of people employed have a detrimental effect on plant operations or maintenance (e.g., not getting the necessary work done)?
2)	Plant Coverage	Is plant coverage adequate such that necessary operational activities are accomplished? Can appropriate adjustments be made during the evenings, weekends or holidays? For example, is staff available to respond to changing raw water quality characteristics during periods of operation?

	3) Work Load Distribution	Does the improper distribution of adequate manpower (e.g. a higher priority on maintenance tasks) prevent process adjustments from being made or cause them to be made at inappropriate times, resulting in poor plant performance?
	4) Staff Turnover	Does a high personnel turnover rate cause operation and/or maintenance problems that affect process performance or reliability?
b.	Morale	
	1) Motivation	Does the plant staff want to do a good job because they are motivated by self-satisfaction?
	2) Pay	Does a low pay scale or benefit package discourage more highly qualified persons from applying for operator positions or cause operators to leave after they are trained?
	3) Environment	Does a poor work environment create a condition for more "sloppy work habits" and lower operator morale?
c.	Staff Qualifications	
	1) Aptitude	Does the lack of capacity for learning or understanding new ideas by critical staff members cause improper O & M decisions leading to poor plant performance or reliability?
	2) Education	Does a low level of education result in poor O & M decisions? Does a high level of education cause needed training to be felt unnecessary?
	3) Certification	Does the lack of adequately certified personnel result in poor O & M decisions?
d.	Productivity	Does the plant staff conduct the daily operation and maintenance tasks in an efficient manner? Is time used efficiently?

DEFINITIONS OF PERFORMANCE LIMITING FACTORS

3. Financial

a. Insufficient Funding	Does the lack of available funds (e.g. inadequate rate structure) cause poor salary schedules, insufficient stock of spare parts that results in delays in equipment repair, insufficient capital outlays for improvements or replacement, lack of required chemicals or chemical feed equipment, etc.?
b. Unnecessary Expenditures	Does the manner in which available funds are utilized cause problems in obtaining needed equipment, staff, etc.? Are funds spent on lower priority items while needed, higher priority items are unfunded?
c. Indebtedness	Does the annual debt payment limit the amount of funds available for other items such as equipment, staff, etc.?
4. Water Demand	Does excessive water use caused by declining rate structure, concessions to industry, or high unaccounted for use exceed the capability of plant unit processes and therefore degrade plant performance?

B. MAINTENANCE

1. Preventive

a. Lack of Program	Does the absence or lack of an effective scheduling and recording procedure cause unnecessary equipment failures or excessive downtime that results in plant performance or reliability problems?
b. Spare Parts Inventory	Does a critically low or nonexistent spare parts inventory cause unnecessary long delays in equipment repairs that result in degraded process performance?

2. Corrective

a. Procedures	Are procedures available to initiate maintenance activities on observed equipment operating irregularities (e.g., work order system)? Does the lack of emergency response procedures result in activities that fail to protect process needs during breakdowns of critical equipment (e.g., maintaining disinfectant or coagulant feeds during equipment breakdowns)?

DEFINITIONS OF PERFORMANCE LIMITING FACTORS

b.	Critical Parts Procurement	Do delays in getting replacement parts caused by procurement procedure result in extended periods of equipment downtime?

3. General

a.	Housekeeping	Does a lack of good housekeeping procedures (e.g., unkempt, untidy, or cluttered working environment) cause an excessive equipment failure rate?
b.	Reference Material	Does the absence or lack of good equipment reference sources result in unnecessary equipment failure and/or downtime for repairs (includes maintenance portion of O & M Manual, equipment catalogs, etc.)?
c.	Staff Expertise	Does the plant staff have the necessary expertise to keep the equipment operating and to make equipment repairs when necessary?
d.	Technical Guidance	Does inappropriate guidance for repairing, maintaining, or installing equipment from a technical resource (e.g., equipment supplier or contract service) result in equipment downtime that adversely affects performance? If technical guidance is necessary to decrease equipment downtime; is it available and retained?
e.	Equipment Age	Does the age or outdatedness of critical pieces of equipment cause excessive equipment downtime and/or inefficient process performance and reliability (due to unavailability of replacement parts)?

DEFINITIONS OF PERFORMANCE LIMITING FACTORS

C. DESIGN

1. Raw Water — Does the presence of raw water quality characteristics over and above what the plant was designed for, or over and above what is thought to be tolerable, cause degraded process performance by any of the items (a-c) listed below?

   a. THM Precursors

   b. Turbidity

   c. Seasonal Variations

   d. Watershed/Reservoir Management — Do facilities exist to control raw water quality entering the plant (e.g. can intake levels be varied, can chemicals be added to control aquatic growth, do watershed management practices adequately protect raw water quality)?

2. Unit Design Adequacy

   a. Pretreatment — Do the design features of any pretreatment unit cause problems in downstream equipment or processes that have led to degraded plant performance?

      1) Intake Structure — Does the design of the intake structure result in excessive clogging of screens, a build-up of silt, or passage of solids that damages downstream processes?

      2) Presedimentation Basin — Does a deficient design cause poor sedimentation that results in poor plant performance (e.g., inlet configuration, size, type, or depth of the basin; or placement or length of the weirs)?

      3) Prechlorination — Does prechlorination cause excessive finished water disinfection byproducts?

   b. Low Lift Pumping — Does the existence of high volume constant speed pumps cause undesirable hydraulic loadings on downstream unit processes?

   c. Flash Mix — Does a lack of or inadequate mixing result in excessive chemical use or insufficient coagulation to the extent that it impacts plant performance?

DEFINITIONS OF PERFORMANCE LIMITING FACTORS

d.	Flocculation	Does the performance of the flocculation unit process contribute to problems in downstream unit processes that have degraded plant performance? Does a lack of flocculation time or flocculation stages with variable energy input result in poor floc formation and degrade plant performance?
e.	Sedimentation	Does a deficient design cause poor sedimentation that results in poor filter performance (e.g., inlet configuration, size, type, or depth of the basin; or placement or length of the weirs)?
f.	Filtration	Does the size of filter, or the type, depth, and effective size of filter media hinder its ability to adequately treat water? Are the surface wash and backwash facilities adequate to maintain a clean filter bed? Have the underdrains or support gravels been damaged or disturbed to the extent that filter performance is compromised?
g.	Disinfection	Do the facilities have any design limitations that contribute to poor disinfection (e.g., proper mixing, detention time, feed rates, proportional feed, etc.)?
h.	Sludge Treatment	Does the type or capacity of sludge treatment processes cause process operation problems that degrade plant performance?
i.	Ultimate Sludge/ Backwash Water Disposal	Are the sludge and backwash water facilities and disposal area of sufficient size and type to ensure that poor plant performance does not occur or applicable permits regulating the discharge are not violated?
j.	Fluoridation	Do the fluoridation facilities have any design limitations that result in an inability to achieve regulated fluoride levels (e.g., feed rates, proportional feed, etc.)?

3. Miscellaneous — The design "miscellaneous" category covers areas of design inadequacy not specified in the previous design categories. (Space is available in the Checklist to accommodate additional items not listed.)

DEFINITIONS OF PERFORMANCE LIMITING FACTORS

a.	Process Flexibility	Do chemical feed facilities have various feed points to optimize treatment (e.g., feed alum and cationic polymers at flash mix, feed non-ionic or anionic polymers at points where mixing is gentle)? Do facilities exist to feed the types of chemicals required to produce a high quality stable finished water (e.g., coagulant aids, flocculant aids, filter aids, stabilization chemicals)?
b.	Process Controllability	Do the existing process control features provide adequate adjustment and measurement of plant flow rate, backwash flow rate, filtration rate, and flocculation mixing inputs? Do chemical feed facilities provide adjustable feed ranges that are easily set for operation at all required dosages? Do chemical feed controls remain set once adjusted or do they vary? Are chemical feed rates easily measured?
c.	Process Automation	Does the lack of needed automatic monitoring or control devices (streaming current detector, continuous recording turbidimeter, etc.) cause excessive operator time for process control and monitoring? Does the automatic operation of critical unit processes degrade plant performance during start-up and shut-down?
d.	Lack of Standby Units for Key Equipment	Does the lack of standby units for key equipment cause degraded process performance during breakdown or during necessary preventive maintenance activities (e.g. backwash pumps and chemical feeders, etc.)?
e.	Flow Proportioning	Does inadequate flow proportioning or flow splitting to duplicate units cause problems or partial unit overloads that degrade effluent quality or hinder achievement of optimum process performance?
f.	Alarm Systems	Does the absence or inadequacy of an alarm system for critical pieces of equipment or processes cause degraded process performance (e.g. raw or finished water turbidity)?
g.	Alternate Power Source	Does the absence of an alternate power source cause problems in reliability of plant operation leading to degraded plant performance?

h.	Laboratory Space and Equipment	Does the absence of an adequately equipped laboratory limit plant performance?
i.	Sample Taps	Does a lack of sample taps on key process flow streams (e.g. individual filters, sedimentation basin solids, backwash recycle streams) for sampling prevent needed information from being obtained?
j.	Plant Inoperability Due to Weather	Are certain units in the plant extremely vulnerable to weather changes and, as such, do not operate at all or do not operate as efficiently as necessary to achieve the required performance? Do poor roads leading into the plant cause it to be inaccessible during certain periods of the year for chemical or equipment delivery or for routine operation?
k.	Return Process Streams	Does excessive volume and/or a highly turbid return process flow stream (e.g. backwash return flow) cause adverse effects on process performance, equipment problems, etc.? Does the inability to measure or sample these streams degrade plant performance?

D. OPERATION

1. Testing

a.	Performance Monitoring	Are plant and distribution system monitoring tests truly representative of performance?
b.	Process Control Testing	Does the absence or wrong type of process control testing cause improper operational control decisions to be made (e.g. does filter performance evaluation support finished water turbidity data)?

2. Process Control Adjustments

a.	Water Treatment Understanding	Is the operator's lack of basic understanding of water treatment (e.g. limited exposure to terminology, lack of understanding of the function of unit processes, etc.) a factor in poor operational decisions and poor plant performance or reliability?

b.	Application of Concepts/Testing to Process Control	Is the staff deficient in the application of their knowledge of water treatment and interpretation of process control testing such that improper process control adjustments are made?
c.	Technical Guidance	Does inappropriate operational information received from a technical resource (e.g. design engineer, equipment representative, regulatory inspector) cause improper operational decisions to be implemented or continued?
d.	Training	Does non-attendance at available training programs result in poor process control decisions by the plant staff or administrators?
e.	Insufficient Time On Job	Does the short time on the job and associated unfamiliarity with plant needs result in the absence of process control adjustments or in improper process control adjustments being made (e.g., opening or closing a wrong valve, turning on or off a wrong chemical feed pump, backwashing a filter incorrectly, etc.)?

3. O & M Manual/Procedures

a.	Adequacy	Does inappropriate guidance provided by the O & M manual/procedures result in poor or improper operation decisions?
b.	Use	Does the operator's failure to utilize a good O & M manual/procedures cause poor process control and poor treatment that could have been avoided?

4. Distribution System — Are distribution system operating procedures adequate to protect the integrity of finished water quality (e.g., flushing, reservoir management, etc.)?

E. MISCELLANEOUS

The "miscellaneous" category allows addition of factors not covered by the above definitions. Space is available in the Checklist to accommodate these additional items.

APPENDIX C

Data Collection Forms

FORM A
KICKOFF MEETING

A. MEETING OUTLINE

1. Purpose of CPE

    a. Background.

    b. Assess plant potential for achieving compliance.

    c. Identify current factors limiting performance.

    d. Outline follow-up activities.

2. Schedule of Events

	DAY	TIME
a. Kickoff Meeting	______________	______________
b. Plant Tour	______________	______________
c. Review Budget/ User Fees/Revenues	______________	______________
d. Onsite Data Collection	______________	______________
e. Personnel Interviews	______________	______________
f. Exit Meeting	______________	______________

3. Information Resources (availability):

    As built construction drawings ______________________________

    O & M Manual ______________________________

    Monitoring records ______________________________

    Equipment literature ______________________________

    Process control records ______________________________

    Budget records ______________________________

    Design consultant ______________________________

FORM A (contd.)
KICKOFF MEETING

B. ATTENDANCE LIST

Municipality: ______________________________ Date: ________________________

	Name	Title/Dept.	Telephone No.
1.			
2.			
3.			
4.			
5.			
6.			
7.			
8.			
9.			
10.			
11.			
12.			
13.			
14.			
15.			
16.			

FORM A (contd.)
KICKOFF MEETING

C. PERSONNEL INTERVIEWS SCHEDULING SHEETS*

Person	Title	Day	Time

*Includes offsite administrators/owners, budgeting personnel, laboratory personnel, maintenance personnel, plant administrators, shift personnel, operators, etc.

FORM B
ADMINISTRATION DATA

A. NAME AND LOCATION:

Name of Facility ______________________________

Owner ______________________________

Administrative Office:

Mailing Address ______________________________

Primary Contact ______________________________

Title ______________________________

Telephone No. ______________________________

Treatment Plant:

Mailing Address ______________________________

Primary Contact ______________________________

Title ______________________________

Telephone No. ______________________________

FORM B (cont.)
ADMINISTRATION DATA

B. ORGANIZATION:

1. Governing Body (Name and Scheduled Meetings):

2. Structure:

   From Governing Body to Plant:

   Within Plant:

3. Staff Meetings (formal/informal):

FORM B (cont.)
ADMINISTRATION DATA

B. ORGANIZATION (cont.):

4. Reporting Requirements (formal/informal):

5. Public Relations/Education:

6. Observations (openness, awareness of plant needs, management style, etc.):

FORM B (cont.)
ADMINISTRATION DATA

C. PERSONNEL:

PLANT

No.	Title/Name	Certification	Pay Scale	% Time at Plant

OFF SITE

No.	Title/Name	Pay Scale	% Time Allocated to Plant

FORM B (cont.)
ADMINISTRATION DATA

D. TRAINING:

Operator Training Budget ____

____

Training Incentives ____

____

Training Over Last Year ____

____

E. PLANT COVERAGE:

Weekdays (shift times/overlap/number per shift):

Weekends and Holidays:

Alarms (on what process? Dialer?):

FORM B (cont.)
ADMINISTRATION DATA

F. PLANT BUDGET/EXPENDITURES:
(Attach copy of actual budget and/or expenditures if available.)

Budget year ____________________ to ____

Expenditure period ______________ to ____

CATEGORY	BUDGET AMOUNT	EXPENDITURE AMOUNT
Administrative Salaries (incl. fringes)	____________	________________
Plant Staff Salaries (incl. fringes)	____________	________________
Utilities		
Electric	____________	________________
Gas	____________	________________
Chemicals	____________	________________
Vehicles	____________	________________
Training	____________	________________
______________________________	____________	________________
______________________________	____________	________________
______________________________	____________	________________
Operations Total	____________	________________

FORM B (cont.)
ADMINISTRATION DATA

G. CAPITAL OUTLAYS:

1. Capital Improvement Reserve (self sustaining utility?, master plan?, replacement philosophy?)

2. Capital Replacement Plan (available?, items scheduled for replacement?, attach if available).

3. Expansion History and Proposed Modifications (historical studies, current evaluations, long range plans, etc.).

FORM B (cont.)
ADMINISTRATION DATA

H. REVENUE:

1. User Charges:

2. Connection Fees:

3. Other Sources of Revenue (interest income, bulk water sales):

FORM B (cont.)
ADMINISTRATION DATA

H. REVENUE (cont.):

4. Total Revenue for Evaluation Period (compare to expenditures):

5. Miscellaneous:

   Are rates and budgets reviewed annually?

   When was last rate increase? (How much?)

   Proposed increases?

FORM C
DESIGN DATA

A. PLANT FLOW DIAGRAM

(Attach if available; include solids handling and chemical feed points.)

B. FLOW DATA:

Design Flow

Average Daily Flow = ___________m^3/d

Maximum Hydraulic Capacity = ___________m^3/d

Operating Flow

Peak Instantaneous Operating Flow = _____________m^3/d

FORM C
DESIGN DATA

C. UNIT PROCESSES

FLOW MEASUREMENT

Flow Stream Measured	Meter Type	Calibration Frequency	Comments
Raw Water:			
Finished Water:			
Backwash:			
Other (Designate):			

Accuracy Check During CPE (Describe):

FORM C
DESIGN DATA

C. UNIT PROCESSES (cont.)

SCREENING

Traveling Bar Screen:

Bar Screen Width = __________ cm

Bar Opening = __________ cm

Screening Disposal:

Operation Problems:

Hand Cleaned Bar Screen:

Bar Screen Width = __________ cm

Bar Spacing = __________ cm

Cleaning Frequency = __________________________

Screening Disposal:

Operation Problems:

Other (Describe):

FORM C
DESIGN DATA

C. UNIT PROCESSES (cont.)

PUMPING

Flow Stream Pumped	Pump Description	# of Pumps	Rated Capacity

Flow Control Method (describe):

Flow Stream Pumped	Pump Description	# of Pumps	Rated Capacity

Flow Control Method (describe):

Flow Stream Pumped	Pump Description	# of Pumps	Rated Capacity

Flow Control Method (describe):

FORM C - DESIGN DATA

C.UNIT PROCESSES (cont.)

PRESEDIMENTATION

Type (eg. concrete or earthen) ______________________________

Number of Basins ________ Surface Dimensions ______________________

Water Depth (Shallowest) = _______ m   Water Depth (deepest) = _______ m

Weir Location __________________   Weir Length = _______ m

Total Surface Area = _______ m^2 Total Volume = _______ m^3

Flow:
Design = _________ m^3/d Operating Flow* = __________ m3/d

Detention Time:
At Design Flow = _________ hr   At Operating* Flow = __________ hr

Weir Overflow Rate:
At Design Flow = _________ $m^3/m/d$ At Operating* Flow = __________ $m^3/m/d$

Surface Overflow Rate:
At Design Flow = _________ $m^3/m^2/d$ At Operating* Flow = __________ $m^3/m^2/d$

Chemical Feed Capability:
Type of Chemicals ______________________________

Operating Range (Describe) ______________________________

Sketch:

*Peak instantaneous operating flow.

FORM C
DESIGN DATA

C. UNIT PROCESSES (cont.)

RAPID MIXING

Rapid Mix:

Type ____
(mechanical, in-line mechanical, in-line static)

Number of Mixers __________ Power Rating ________________

Number of Basins _______ Surface Dimensions _____________

Water Depth = _______ m Total Volume = _______ m^3

Flow:

Design = __________ m^3/d Operating* = __________ m3/d

Detention Time:

At Design Flow = __________ s At Operating* Flow = __________ s

G Value (see page C-21):

At Design Flow = __________ s^{-1} At Operating* Flow = __________ s^{-1}

Operating Problems:

*Peak instantaneous operating flow.

FORM C
DESIGN DATA

C. UNIT PROCESSES (cont.)

Calculation of G Value:

$G = (P/\mu V)^{1/2}$

where:

> G = velocity gradient (s^{-1}); P = power input (Watts or N*m/s);
> μ = dynamic viscosity (kg/m*s); V = volume (m^3)

For example:

Calculate G for an in line mixer with power of 0.75 hp, volume = 0.95 ft^3, and water temperature = 10°C.

> Power Input = 0.75 hp x 746 W/hp = 559.3 W
>
> Mixer Volume = 0.95 ft^3 x 0.0283 m^3/ft^3 = 0.027 m^3
>
> Viscosity @ 10°C = 1.308×10^{-3} kg/m*s (from table below)

Therefore;

> $G = [559.3/(0.001308*0.027)]^{1/2} = 3{,}980\ s^{-1}$

Table of Dynamic Viscosity of Water vs. Temperature

Temperature (°C)	Dynamic Viscosity (kg/m*s)
0	1.794×10^{-3}
5	1.519×10^{-3}
10	1.308×10^{-3}
15	1.140×10^{-3}
20	1.005×10^{-3}
25	8.940×10^{-4}
30	8.010×10^{-4}

FORM C
DESIGN DATA

C. UNIT PROCESSES (cont.)

FLOCCULATION

Type (e.g. paddle wheel, turbine, hydraulic) ______________________________

Control (e.g. constant or variable speed) ______________________________

Stages (sketch below)

Stage	Surface Dimensions	Depth	Volume	Power	G Value
1	________	________	________	________	________
2	________	________	________	________	________
3	________	________	________	________	________
4	________	________	________	________	________
Total:					

Flow: Design = __________ m^3/d Operating* = __________ m^3/d

Detention Time: At Design Flow = ________ min. At Operating* Flow = ________ min.

Operating Problems:

Sketch:

*Peak instantaneous operating flow.

FORM C
DESIGN DATA

C. UNIT PROCESSES (cont.)

SEDIMENTATION

Number of Basins _____ Surface Dimensions ___________________________________

Water Depth (Shallowest) = ______ m   Water Depth (Deepest) = ______ m

Weir Location ___________________________________ Weir Length = ______m

Total Surface Area = __________ m^2 Total Volume = __________ m^3

Flow:
Design = __________ m^3/d Operating* = __________ m^3/d

Detention Time:
At Design Flow = ________ hr.   At Operating* Flow = __________ hr.

Surface Overflow Rate:
At Design Flow = ________ $m^3/m^2/d$ At Operating* Flow = __________ $m^3/m^2/d$

Weir Overflow Rate:
At Design Flow = ________ $m^3/m/d$ At Operating* Flow = __________ $m^3/m/d$

Inlet/Outlet Conditions (Describe and/or sketch):

Operating Problems:

*Peak instantaneous operating flow.

FORM C
DESIGN DATA

C. UNIT PROCESSES (cont.)

FILTRATION

Type of Filters (media type, pressure or gravity etc.) ____________________
Number of Filters ________ Surface Dimensions ____________________
Total Surface Area ____________________ m^2

Media Characteristics:

Media Type	Depth (cm)	Uniformity Coefficient	Effective Size	Specific Gravity
________	________	________	________	________
________	________	________	________	________
________	________	________	________	________
________	________	________	________	________

Flow:
Design = __________ m^3/d Operating* = __________ m^3/d

Filtration Rate:
At Design Flow = __________ $m^3/m^2/d$ At Operating* Flow = ________ $m^3/m^2/d$

Filter Control (e.g. declining or constant rate/level etc.): ____________________

Available Headloss: ________ m

Surface Wash:
Type (e.g. rotary, fixed, manual) ____________________
Water Flow Rate = ________ m^3/d Surface Wash Rate = ________ $m^3/m^2/d$
Wash Duration = __________ min

Backwash:
Water Wash Rate:
At Design Flow = __________ $m^3/m^2/d$ At Operating* Flow = ________ $m^3/m^2/d$
Duration = __________ min

*Peak instantaneous operating flow.

FORM C
DESIGN DATA

C. UNIT PROCESSES (cont.)

FILTRATION (cont.)

Air Wash Rate:
At Design Flow = ________ $m^3/m^2/min$ At Operating* Flow = ______ $m^3/m^2/min$

Control/Operating Problems:

Mud Balls:

Dirty Media:

Uneven Media:

Backwash Rate Control/Procedure (e.g., gradual start/stop):

Filter Rate Control/Procedure (e.g., gradual changes):

Hydraulic Loading During Backwash (e.g., reduce flow to remaining filters?):

Air Bubbles During Backwash:

Surface Wash Control/Procedure:

Other:

Availability of Sample Taps (e.g. backwash and individual filters):

*Peak instantaneous operating flow.

FORM C
DESIGN DATA

C. UNIT PROCESSES (cont.)

DISINFECTION

Contact Basin(s) Available (e.g. clearwell) ______________________________

Basin	Surface Dimensions	Depth	Volume
________	____________	______	_________
________	____________	______	_________
________	____________	______	_________
		Total:	_________

Detention Time:

(Theoretical)[a] __________ min.
(Functional)[b] __________ min.

[a] Based on total available volume and peak instantaneous operating flow.

[b] Based on evaluation of operating variables such as basin baffling, minimum operating depth, and transmission line length to first user. Utilize the table below to determine the factor to be multiplied by the actual volume to accommodate baffling consideration.

FACTORS TO DETERMINE EFFECTIVE VOLUME FROM ACTUAL VOLUME BASED ON BAFFLING CHARACTERISTICS

Baffling Condition	Factor	Baffling Description
Unbaffled	0.1	None, agitated basin, high inlet and outlet flow velocities, variable water level.
Poor	0.3	Single or multiple unbaffled inlets and outlets, no intrabasin baffles.
Average	0.5	Baffled inlet or outlet with some intrabasin baffling; may be used for floc/sed basins when assessing prechlorine.
Superior	0.7	Perforated inlet baffle, serpentine or perforated intrabasin baffles, outlet weir or perforated weir.
Excellent	0.9	Serpentine baffling throughout basin.

FORM C
DESIGN DATA

C. UNIT PROCESSES (cont.)

Chlorinator(s):

No. of Chlorinators ______________________________

Description (make/type etc.) ____

Capacity _______ to _______ kg/d

Flow Proportioned? ______________________________

Flow:

Design = __________ m^3/d Operating* = __________ m^3/d

Maximum Dosage Capability:

At Design Flow = __________ mg/L At Operating* Flow = __________ mg/L

Operating Problems:

*Peak instantaneous operating flow.

FORM C
DESIGN DATA

C. UNIT PROCESSES (cont.)

CHEMICAL FEED CAPABILITY

Metal Salts:

DRY:

Type	Design Feed Range (kg/h)	Dosage Range at Design Flow (mg/L) min.	max.	Dosage Range at Oper.* Flow (mg/L) min.	max.
______	______	______	______	______	______
______	______	______	______	______	______

LIQUID:

Type	Design Feed Range (ML/min)	Dosage Range at Design Flow (mg/L) min.	max.	Dosage Range at Oper.* Flow (mg/L) min.	max.
______	______	______	______	______	______
______	______	______	______	______	______

Dosage Control (Describe):

Operating Problems:

Accuracy Check During CPE (Describe):

*Peak instantaneous operating flow.

FORM C
DESIGN DATA

C. UNIT PROCESSES (cont.)

Polymers:

Type	Design Feed Range (mL/min)	Stock[a] Solution (%W/V)	Recomm.[b] Dilution (%W/V)	Dosage Range at Design Flow (mg/L) min.	max.	Dosage Range at Oper.*Flow (mg/L) min.	max.

(a) Obtain from manufacturer's data sheet.
(b) Obtain from manufacturer's data sheet.

Dosage Control (Describe for each):

Operating Problems:

Accuracy Check During CPE (Describe):

*Peak Instantaneous Operating Flow.

FORM C
DESIGN DATA

C. UNIT PROCESSES (cont.)

pH/Alkalinity Adjustment:

Chemicals Used:

Dosage Control (Describe):

Operating Problems:

Fluoridation:

Fluoride Compound Used:

Dosage Control (Describe):

Operating Problems:

Softening:

Chemicals Used:

Dosage Control (Describe):

Operating Problems:

Powdered Activated Carbon:

Dosage Control (Describe):

Operating Problems:

Other:

FORM C
DESIGN DATA

C. UNIT PROCESSES (cont.)

SOLIDS HANDLING

Presedimentation Sludge:

Description of Pumping Procedure (eg. time clocks, variable speed pumps):

Method of Waste Volume Measurement:

Sampling Location:

Sampling Procedure:

Operating Problems:

Sedimentation Sludge:

Description of Pumping Procedure (eg. time clocks, variable speed pumps):

Method of Waste Volume Measurement:

Sampling Location:

Sampling Procedure:

Operating Problems:

FORM C
DESIGN DATA

C. UNIT PROCESSES (cont.)

SOLIDS HANDLING (cont.)

Return Sludge (Solids Contact Unit):

Description of Sludge Movement:

Controllable Capacity Range: Low = ________ m^3/d High = ________ m^3/d

Method of Control:

Sampling Location:

Sampling Procedure:

Operating Problems:

Sludge Drying Beds/Lagoons:

No. of Beds/Lagoons ________ Dimensions ________________________________

Total Volume __________ Subnatant Drain To ________________________________

Dewatered Sludge Removal:

Mode of Operation: (depth of sludge draw, seasonal operation, include sketch):

Operating Problems:

FORM C
DESIGN DATA

C. UNIT PROCESSES (cont.)

SOLIDS HANDLING (cont.)

Other Dewatering Unit(s):

Type of Unit(s) ______________________________ No. of Units _______

Loading Rate:
At Design Flow = __________ mg/L At Operating* Flow = __________ mg/L

Polymer Used ____________________________
Dosage = __________________ g/kg dry wt.

Cake Solids ________________ % solids

Hours/Week of Operation:
Design _________________
Operating ______________

Operating Problems:

Ultimate Sludge Disposal:

Description:

Operating Problems:

*Peak instantaneous operating flow.

FORM C
DESIGN DATA

D. MISCELLANEOUS DESIGN INFORMATION

Process Automation (describe existing systems):

Standby Units (chemical feed, backwash pumps):

Flow Proportioning to Units:

Alarm Systems (description of systems, units covered):

Alternate Power Source:

Weather Inoperability:

Return Process Streams:

FORM D
OPERATIONS DATA

A. PROCESS CONTROL STRATEGY AND DIRECTION

Who sets major process control strategies and decisions?

Who makes process control decisions when lead process control person is not at plant?

Where is help sought when desired performance is not achieved?

Are staff members asked their opinions?

How is communication conducted between laboratory, operations and maintenance?

B. SPECIFIC PROCESS CONTROL PROCEDURES

Sampling and Testing:

Sampling Locations (add to plant flow schematic):

Presedimentation:

Sludge Removal (method of control/adjustment):

Performance Monitoring:

Other:

FORM D (cont.)
OPERATIONS DATA

B. SPECIFIC PROCESS CONTROL PROCEDURES (cont.)

Sedimentation:

Performance Monitoring (tests used; solids balance):

Sludge Removal (method of control/adjustment):

Sludge Recyle (contact sedimentation):

Other:

Filtration:

Hydraulic Loading Rate Control (method of control/adjustment):

Backwash Control (test used, method of determining frequency):

Filter Monitoring:

- Influent Turbidity
- Effluent Turbidity
- Headloss
- Loading Rate
- Length of Run

Coagulation/Turbidity Removal:

Feed Rate Control (method of control/adjustment):

Performance Monitoring:

- Jar Test
- Pilot filter
- Zeta Meter
- Streaming Current Detector
- Turbidity

FORM D (cont.)
OPERATIONS DATA

B. SPECIFIC PROCESS CONTROL PROCEDURES (cont.)

Disinfection:

Performance Monitoring (tests used):

Feed Rate Control (method of control, adjustment):

Fluoridation:

Performance Monitoring (tests used):

Feed Rate Control (method of control, adjustment):

pH/Alkalinity Adjustment:

Performance Monitoring (tests used):

Feed Rate Control (method of control, adjustment):

Softening/Recarbonation:

Performance Monitoring (tests used):

Feed Rate Control (method of control, adjustment):

FORM D (cont.)
OPERATIONS DATA

B. SPECIFIC PROCESS CONTROL PROCEDURES (cont.)

Taste and Odour:

Performance Monitoring (tests used):

Feed Rate Control (method of control, adjustment):

Sludge Handling and Disposal:

Sludge Dewatering (Monitored, process control/optimization):

Sludge Disposal (Meet requirement, monitoring, options):

Other:

Miscellaneous:

Data Development/Interpretation:

Trend Charts:

FORM D (cont.)
OPERATIONS DATA

C. PROCESS CONTROL REFERENCES

(Specifically note sources (e.g., publications or personnel) that are the cause of poor process control decisions or strategies, suspected or definitely identified):

D. OPERATIONS AND MAINTENANCE MANUAL

Adequacy:

Use:

FORM D (cont.)
OPERATIONS DATA

E. LABORATORY CAPABILITY

1. Facilities

	Adequate Yes	Adequate No	Comments
Bench space			
Storage space			
Floor area			
Lighting			
Electricity			
Potable water supply			
Compressed air			
Vacuum			
Chemical fume hood			
Air conditioning			
Desk			
Records storage			

2. Equipment & Instruments

	Available Yes	Available No	Comments
Turbidimeter			
Core sampler			
pH meter			
Centrifuge			
Distilled water (source)			
Drying oven			
FC water bath incubator			
Coliform water bath incu.			
Hot air oven			
Refrigerator			
Autoclave			
Analytical balance			
Microscope			
Desiccator			
Automatic samplers			
Spectrophotometer			
Conductivity meter			
Jar test apparatus			
Titration burets			
Erlenmeyer flasks			
Volumetric flasks			

FORM D (cont.)
OPERATIONS DATA

E. LABORATORY CAPABILITY (cont.)

2. Equipment & Instruments

	Available Yes	Available No	Comments
Beakers			
Evaporating dishes			
Zeta meter			
Particle counter			

3. Analytical Capability

	Available Yes	Available No	Comments
Calcium			
Magnesium			
Hardness			
Sodium			
Alkalinity			
Temperature			
pH			
Turbidity			
Iron			
Manganese			
Chloride			
Sulfate			
Nitrate			
Total Coliform			
Heterotrophic plate count			
Conductivity			
Total dissolved solids			
Trace inorganics			
Organics			

FORM D (cont.)
OPERATIONS DATA

E. LABORATORY CAPABILITY (cont.)

4. Miscellaneous

Quality Control:

Reference Standards:

Duplicate Tests (schedule, records, etc.):

Standard Procedures/References:

Standard Methods:

Site Specific Procedures:

Training:

FORM E
MAINTENANCE DATA

A. PREVENTIVE MAINTENANCE PROGRAM:

Program Description:

Method of Scheduling:

Method of Documenting Work Completed:

Method of Factoring Costs for Parts/Equipment Into Budgeting Process:

Spare Parts Inventory:

References:

O & M Manual:

Accurate Record Drawings:

Manufacturer's Literature:

Adequacy of Following Resources:

Outside Support:

Tools/Lubricants:

Work Area:

FORM E (cont.)
MAINTENANCE DATA

B. EMERGENCY MAINTENANCE PROGRAM:

Priority Setting (relationship to process control decisions):

Extent of On Site Capability:

Method of Initiating Work Activities (work order):

Critical Parts Procurement (policy restrictions, sources):

Comments:

FORM E (cont.)
MAINTENANCE DATA

C.GENERAL

Equipment or Processes Out of Service Due to Breakdowns (Identify equipment or process, description of problem, length of time out of service, what has been done, what remains to be done, estimated time before repair, how it affects performance):

During the CPE (List and explain):

During the Last 12 Months (List and Explain):

FORM F
PERFORMANCE DATA

A. SOURCE OF DATA: (eg. plant records, MOEE DWSP reports)

B. FLOW DATA:

Mo/Yr	FLOW min.	FLOW avg.	FLOW max.	Operating Time	Inst. Peak Operating Flow
______	______	______	______	______	______
______	______	______	______	______	______
______	______	______	______	______	______
______	______	______	______	______	______
______	______	______	______	______	______
______	______	______	______	______	______
______	______	______	______	______	______
______	______	______	______	______	______
______	______	______	______	______	______
______	______	______	______	______	______
______	______	______	______	______	______
______	______	______	______	______	______
Avg.:	______	______	______	______	______
Peak:				______	______

Instantaneous plant operating flow is the peak flow rate that the unit processes experience on a sustained basis. For example, if a plant treats 5,000 m^3 during its daily 12 hour (0.5 day) operating period, then the instantaneous peak operation flow would be 5,000 m^3 ÷ 0.5 d = 10,000 m^3/d. Judgment of the evaluator is essential in selecting the instantaneous peak operating flow because of variations in flow that can occur by operating different pumps or changing unit processes that are in service.

FORM F (cont.)
PERFORMANCE DATA

C. DEMAND EVALUATION

Number of Taps Served __________ Population Served __________

Major Industrial Users (include name and volume used):

Per Capita Consumption:

Average:

Peak:

Typical per capita water consumption values are shown below:

Type of Consumption	Lpcd (Range)	Lpcd (Avg.)
Domestic/Residential	76 - 340	208
Commercial	38 - 492	76
Industrial	76 - 303	189
Public	19 - 76	38
Water Unaccounted For	19 - 114	57
	227-946	568

SOURCE: G.M. Fair, J.C. Geyer, and D.A. Okun, Elements of Water Supply and Wastewater Disposal, 2nd ed., Wiley, New York (1971).

D. UNACCOUNTED FOR WATER EVALUATION

Total production of plant ____________ m^3

Total metered water in system __________ m^3

Difference __________ m^3

% Unaccounted = Difference/Total Production x 100 = ____ %

NOTE: Typical unaccounted for water is 10 percent.

FORM F (cont.)
PERFORMANCE DATA

E. BACKWASH WATER EVALUATION

Total volume of filtered water ______ m^3 Total volume of backwash water ______ m^3

Difference __________ m^3

% BW Water = Diffence/Total Volume of Filtered Water x 100 = ______%

NOTE: Typical amount of backwash water is 2% to 6% for conventional plants. Direct filtration plants often exceed this depending on raw water quality.

F. RAW WATER QUALITY

	TURBIDITY					
Mo/Yr	min.	avg.	max.	Temp.	pH	Alkalinity
Avg.						

FORM F (cont.)
PERFORMANCE DATA

G. REPORTED OPERATING DATA FOR PREVIOUS 12 MONTHS

	SETTLED WATER TURBIDITY			FINISHED WATER TURBIDITY		
Mo/Yr	min.	avg.	max.	min.	avg.	max.
Avg.						

FORM F (cont.)
PERFORMANCE DATA

H. CHEMICAL CONSUMPTION:

Type of Chemical ______________________________

Unit Cost ______________________

MO/YR	CHEMICAL USE PER MONTH (L or kg/month)	COMMENTS
Total		

Type of Chemical ______________________________

Unit Cost ______________________

MO/YR	CHEMICAL USE PER MONTH (L or kg/month)	COMMENTS
Total		

FORM F (cont.)
PERFORMANCE DATA

H. MOEE DRINKING WATER SURVEILLANCE PROGRAM (DWSP)

If available, review previous three years of DWSP data to identify water quality concerns, including the distribution system, that are not evident from the review of in-plant monitoring data.

J. PERFORMANCE ASSESSMENT

Develop graphs to depict plant performance. Possibilities are:

1. Plant effluent turbidity versus time for weeks or months with maximum recorded turbidities. Isolate shorter time frames on graph after reviewing data.

2. Filter effluent turbidity versus time to assess recovery time following backwashing a filter or starting a dirty filter.

3. Probability plots to show percentage of time turbidity exceeds desired objective.

4. Long term plots of raw water and finished water turbidities to assess process control.

5. Long term plots of finished water turbidity to assess stability of operation.

K. PERFORMANCE VIOLATIONS WITHIN LAST 12 MONTHS:

FORM G
INTERVIEW DATA

A. INTERVIEW CONCERNS

Interviews are used to obtain feedback in the four categories of administration, design, operation, and maintenance. The following items are presented to assist the interviewers in obtaining this feedback.

1. Administration

Owner Responsibility
- Attitude toward staff? regulatory agency? consultants?
- Self-sustaining facility attitude?
- Policies?
- Communications (formal/informal)?

Performance Goal
- Is plant in compliance?
  - If yes, what's making it that way?
  - If no, why not?
- Is regulatory pressure felt for performance?
- What are performance requirements?

Administrative Support
- Budget
  - Within range of other plants?
  - Covers capital improvements?
  - Unnecessary expenditures?
  - Sufficient?
  - Attitude toward rates?

Personnel
- Within range of other plants?
- Allows adequate time?
- Motivation, pay, supervision, working conditions?
- Productivity? Turnover? Training Support?

Involvement
- Visits to treatment plant?
- Awareness of facility performance?
- Request status reports (performance and cost-related)?
- Familiarity with plant needs?

FORM G (cont.)
INTERVIEW DATA

A. INTERVIEW CONCERNS (cont.)

2. Design
    - Raw water quality problems?
    - Equipment problems?
    - Status of warranties?
    - Return process streams?
    - Preliminary treatment?
    - Coagulation/flocculation?
    - Sedimentation?
    - Filtration?
    - Chemical feed?
    - Advanced treatment techniques?
    - Disinfection?
    - Sludge handling and disposal?
    - Flow measurement?
    - Flow splitting?
    - Alarms or alternate power?

3. Operation
    - Communication of decisions?
    - Key control parameters?
    - Involvement of staff?
    - Laboratory quality?
    - Administrative support?
    - Staffing?
    - Performance problems?
    - Unit process optimization?
    - External support?
    - Process control testing/adjustments?
    - O & M manual/references?

4. Maintenance
    - How are priorities set?
    - Attitude toward program?
    - Emergency versus preventative?
    - Reliability (spare parts or critical part procurement)?
    - Staffing?
    - Equipment accessibility?

FORM G (cont.)
INTERVIEW DATA

B. PERSONNEL INTERVIEWS

Name: ____

Title: ____

Certification: ____

Years at Plant: __________ Years of Experience: ______________________

Area of Responsibility: ____

Training: ____

Concerns/Recommendations (Administration, Design, Operation & Maintenance):

FORM H
EXIT MEETING

ATTENDANCE LIST

Municipality: ______________________ Date: ______________________

	Name	Title/Dept.	Telephone No.
1.	________	________	________
2.	________	________	________
3.	________	________	________
4.	________	________	________
5.	________	________	________
6.	________	________	________
7.	________	________	________
8.	________	________	________
9.	________	________	________
10.	________	________	________
11.	________	________	________
12.	________	________	________
13.	________	________	________
14.	________	________	________
15.	________	________	________

Attach Copy of Exit Meeting Handouts

APPENDIX D

Example CPE Scheduling Letter and

Letter to MOEE Regarding Project Approval

(From CPE Team)

Date

Address of Municipality

Re: Evaluation of the XYZ Drinking Water Treatment Plant on Month/Day/Year

Dear Official:

This letter is intended to provide you with some information on the evaluation and describe the activities in which you will be involved. We expect that this evaluation will enable your water plant to attain significantly improved performance.

The evaluation procedure that will be used is the first phase of the Composite Correction Program (CCP) approach. The CCP approach has been successfully used in the United States to bring existing plants into compliance with their regulations. In this first phase, which is known as the Comprehensive Performance Evaluation (CPE), all aspects of the design, operation, maintenance, and administration of the plant will be reviewed and evaluated with respect to their impact on performance.

The CPE will begin with a brief kickoff meeting on ___________ at approximately (8:00 a.m. or 4:00 p.m.). The purpose of the kickoff meeting is to explain to the operations staff and plant administration the methods used in conducting the evaluation and the types of activities which will occur during the three days. Any questions and concerns regarding the CPE can also be raised at this time. It is important that the plant administrators and those persons responsible for plant budgeting and planning be present because the CPE will focus a significant effort in reviewing these aspects of the plant. Following the kickoff meeting, which should last approximately 30 minutes, the plant staff will be requested to take the CPE team on an extensive plant tour. After the plant tour, the team will begin collecting performance and design data. Please make arrangements so that the operating records and any design information for the plant are available. These activities will be continued through the second day.

As far as the types of information and records that will be reviewed during the CPE, we will first need to review your monitoring reports for the last 12 months. Any laboratory and plant log sheets covering this same period will be useful as well as any drawings and specifications for the treatment plant. We will also need budget and financial information. This will centre around the budget for the treatment plant and information on salaries, operating funds available, etc. It is our experience that the information we need is usually readily available from existing reports. We usually work with the information available and do not request the administration staff prepare additional summaries of the information.

On the third day the CPE team will be involved in several different activities. The major involvement of the plant staff will be in individual interviews. The plant administrators will also be interviewed and the financial records of the plant reviewed. Several special studies may also be completed by the CPE team to investigate the performance capabilities of the plant's different unit treatment processes. We request that each member of the operations staff be available some time during the day for the interviews. We would also appreciate having an operator available to answer questions about the plant and to operate the plant during the special studies. We will be flexible in working these interviews and special studies around the other required duties of you and your staff.

The last day of the CPE will consist of an exit meeting. During the exit meeting the results of the evaluation will be discussed with all of those who participated. The performance capabilities of the treatment processes will be presented and any factors found to limit the performance of the plant discussed. The CPE team will also answer any questions regarding the results of the evaluation. The results presented in the exit meeting will form the basis of the final report, which will be provided in about six weeks. We expect to begin the exit meeting at 8:00 a.m. on ______________ and it should last approximately one hour.

Yours Very Truly,

(From CPE Team or Municipality/Utility. Please note that this letter is written as if a CPE has already been completed and a CTA is planned. If contact is made with MOE before the CPE begins, the letter must be changed to reflect the timing.)

Date

Addresses of MOE District Office and MOE Approvals Branch

Re: Certificate of Approval Requirements for Technical Assistance Program at the XYZ Water Treatment Plant

Dear District Manager/Water and Wastewater Manager:

This letter is intended to provide you with general information on the evaluation that was done at the XYZ plant on ____________ and the follow-up technical assistance that is planned.

The evaluation procedure that was used at the XYZ plant was the Comprehensive Performance Evaluation (CPE) approach, which has been successfully used elsewhere to bring existing plants into compliance. During this evaluation, all aspects of the design, operation, maintenance, and administration of the XYZ plant were reviewed and evaluated with respect to their impact on performance.

The next phase of our work will involve on-site technical assistance to address the maintenance, administrative, operations, and design-related factors that are adversely affecting finished drinking water quality. This work will likely require us to make some equipment and/or operational changes, and the on-site assistance should last for six months. We anticipate the following changes will be made:

(List here in bullet format)

Please respond soon and let us know which changes will require an amended Certificate of Approval and what we are responsible for. I can be reached at (xxx) yyy-zzzz if you require more information.

Yours Very Truly,

APPENDIX E

Example CPE Report

RESULTS OF THE COMPREHENSIVE PERFORMANCE EVALUATION OF THE ABC WATER TREATMENT PLANT MUNICIPALITY OF XYZ XYZ, ONTARIO

November 1995

CONTENTS

FIGURES

TABLES

1.0 *INTRODUCTION*

1.1 *Composite Correction Program*

The Composite Correction Program (CCP)[1] is an approach developed by the U.S. Environmental Protection Agency (USEPA) to improve surface water treatment plant performance and to achieve compliance with their Surface Water Treatment Rule (SWTR). The approach consists of two components, the Comprehensive Performance Evaluation (CPE) and the Comprehensive Technical Assistance (CTA). A CPE is a thorough evaluation of an existing treatment plant, resulting in a comprehensive assessment of the unit process capabilities and the impact of the operation, maintenance, and administrative practices on performance of the plant. A CTA is used to improve performance identified during the CPE. Therefore, the CCP approach can be utilized to evaluate the ability of a water filtration plant to meet turbidity and disinfection requirements and then to facilitate the achievement of cost-effective compliance.

In recent years the CCP has gained in prominence as a mechanism that can be used to assist in optimizing the performance of existing surface water treatment plants to levels of performance that exceed regulatory requirements.

The Municipality of XYZ and the Ontario Ministry of Environment and Energy (MOEE) recognized that optimizing performance of its surface water treatment plants was an important safeguard that could be pursued to ensure the protection of the public health. As such, they developed a partnership to pursue the development of CCP capability within the municipality and the Province. As a first component of this partnership effort, selected personnel are being trained to conduct CPE's at two surface water treatment plants within the municipality. The training that is being provided for the municipality and the MOEE was arranged by the project consultant. The training was led by Process Applications, Inc. who developed the CCP approach for the U.S. EPA. It is envisioned that use of CCP components will be an integral part of the effort to optimize the performance of the municipality's surface water treatment plants.

The following report documents the findings of a CPE conducted at the ABC water treatment facility from September 18 - 21, 1995. The CPE was the first of the two training CPEs to be conducted.

---

[1] Renner, R. C., B. A. Hegg, J. H. Bender, and E. M. Bissonette, Handbook - Optimizing Water Treatment Plant Performance Using the Composite Correction Program, EPA 625/6-91/027, U. S. EPA, Cincinnati, Ohio (February 1991).

1.2 *General Facility Information*

The ABC WTP comprises two conventional treatment trains, essentially two plants, with a common raw water source and treated water reservoir. Plant 1 was constructed around 1926; Plant 2 was added in 1958 for an additional 25% capacity. The coagulation/sedimentation process train in Plant 1 was modified in 1980 to provide more flocculation capacity.

Treatment includes coagulant chemical feed (alum or acidified alum and seasonal powdered activated carbon (PAC)), flocculation, sedimentation and dual media filtration - there is one multi-media filter - and chlorination (prechlorination when PAC is not used and post chlorination when the PAC is added).

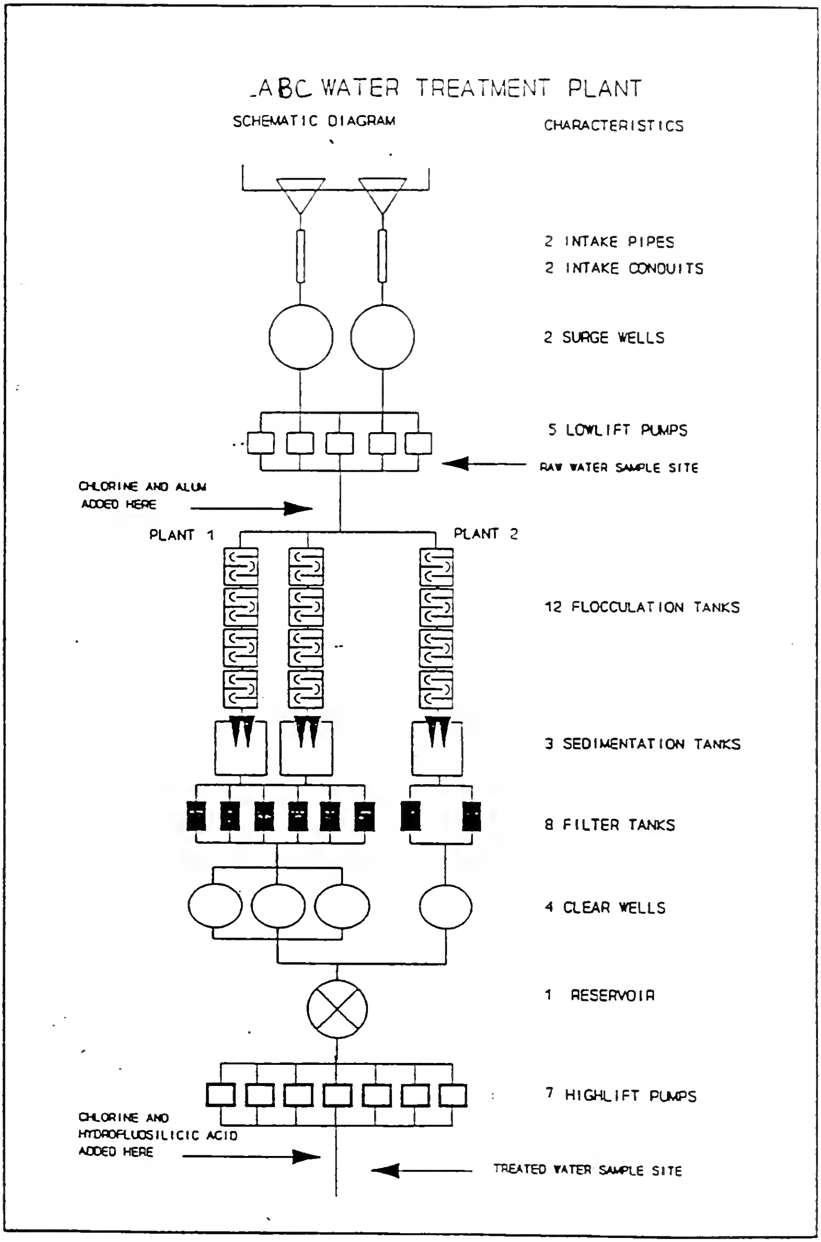
The total design capacity is 109 ML/day with Plant 1, providing approximately 82 ML/day of treatment capacity and Plant 2 providing about 27 ML/day of treatment capacity.

Raw water is supplied from an old canal which is basically a backwater of the "new" canal. The old canal can act as a major raw water settling basin as the water flows from the new canal to the plant and then into an adjacent river.

Raw water quality is generally good with more variability in the winter months, when turbidities average 4 NTU with periodic excursions to a maximum between 15 and 20 NTU. The summer months have more stable raw water quality with turbidities around 2-3 NTU.

A flow schematic of the plant is presented in Figure 1.

FIGURE 1 - ABC WTP SCHEMATIC



2.0 *FACILITY DESIGN DETAILS*

Key design data were collected during the three-day CPE and are presented in Table 1. The plant was evaluated against the 102 ML/day Peak Instantaneous Operating Flow (PIOF) as identified from the records for the last ten years. It is worth noting that the plant's PIOF over the previous 12 months had been 86.5 ML/day and that the design flow is higher than the PIOF at 109 ML/day.

Table 1
Facility Design Details

Types of Flow	
Design Flow	109 ML/day
PIOF	102 ML/day
Raw Water Intake	5 Pumps: 32.7 ML/day 26 ML/day 39 ML/day 14.4 ML/day 34 ML/day For a total of 146.1 ML/day
Raw Water Flow Measurement	Venturi meters to each plant
Flocculation Plant 1	Two identical trains for a total volume of 1200 m^3
Flocculation Plant 2	388 m^3
Sedimentation Plant 1	Two identical trains with a total surface area of 625.54 m^2
Sedimentation Plant 2	Two "stacked" basins with an effective setting area of 446 m^2
Filtration Plant 1	Six dual media with a total area of 343 m^2
Filtration Plant 2	One dual media and one multi-media (with garnet sand) with a total area of 96 m^2

Table 1 Facility Design Details	
Types of Flow	
Backwash	Two pumps each 56.16 ML/day - (650 L/sec)
Reservoir	Volume of 3241 m^3; serpentine baffled basin
Treated Water Pumps	Seven (7) pumps: Two 19.6 ML/day Two 5.42 ML/day 2.75 ML/day 34.66 ML/day 32.7 ML/day For a total of 120.15 ML/day.
Chemical Feed Pumps (duty and standby)	Liquid Alum Liquid Hydrofluosilicic Acid Liquid Sodium Hypochlorite Powdered Activated Carbon Slurry

3.0 *PERFORMANCE ASSESSMENT*

During the CPE the capability of the ABC was evaluated to assess whether the facility, under existing conditions, could comply with the turbidity and disinfection requirements that are used to define optimized performance. Optimized performance, for purposes of this CPE, represents performance criteria that exceeds the Ontario Drinking Water Objectives. A preliminary definition of optimized performance was established by the project Partners during a Protocol Development Workshop held in August 1995.

The optimized performance values were as follows:

1. Sedimentation:

   - <2 NTUs average
   - <5 NTUs as peaks

2. Filtration:

- <0.1 NTU from individual filters
- <0.2 NTU spike for less than 20 minutes following a backwash

3. Disinfection:

- to be based on the USEPA concentration - time (CT) concept, discussed later in Section 4 - the Major Unit Process Evaluation.

Based on this preliminary protocol, optimized performance would require that the facility take a raw water source of variable quality and consistently produce a high quality, finished water. Multiple treatment processes (flocculation, sedimentation, and filtration) are provided in series to remove turbidity, cysts, and other microorganisms followed by disinfection to inactivate any remaining microorganisms. Each of these processes represents a barrier to prevent the passage of cysts and other microorganisms through the plant. By providing multiple barriers, any microorganisms passing one process will be removed in the next, minimizing the likelihood of microorganisms passing through the entire treatment system and surviving in water supplied to the public. All treatment processes in the plant must be capable of providing a barrier at all times because even temporary loss of a barrier could result in the passage of microorganisms into the distribution system and represents a potential health risk to the community.

A major component of the CPE process is an assessment of past and present performance of the plant. This performance assessment is intended to identify if specific unit treatment processes are providing multiple barrier protection through optimum performance. The performance assessment is based on data from plant records and data collected during special studies performed during the CPE.

The ABC operations staff measures the turbidity of the raw, settled, and finished waters throughout each day and records this information on daily log sheets. The data then serves as the basis of the monthly monitoring reports. During the CPE, raw water turbidity values from the monthly reports for the most recent twelve months (e.g., September 1, 1994 through August 31, 1995) were used to assess raw water quality. Performance out of the combination sedimentation units and filtered water from the plant clearwells were also evaluated based on data from the daily log sheets. Individual filter performance is not routinely monitored. It is noted that the evaluation of settled and finished water quality was based on the maximum turbidity values measured each day. Maximum values were used to assess if these unit processes were providing the consistent performance needed for optimized performance and maximum public health protection.

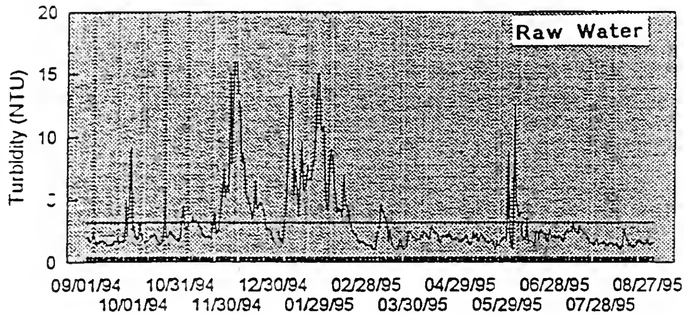
The raw water turbidities for the most recent twelve months are shown in Figure 2. This data shows that the average raw water turbidity was less than 5 NTU, which indicates that the plant routinely receives a relatively good quality raw water. However, Figure 2 does indicate variability in raw water quality, which requires process control adjustments to maintain consistent treatment.

The daily maximum settled turbidity for the sedimentation basins associated with each plant are also shown in Figure 2. The settled water turbidity varied widely for each of the units. Often the turbidity values were in excess of the desired maximum of 2 NTU. The variability in settled water also seemed to trend with the variability of the raw water indicating that process adjustments are not optimized.

The daily maximum finished water turbidity is also shown in Figure 2. A variable finished water quality is indicated. The level of performance depicted meets the Provincial Drinking Water Objectives but does not meet the optimized performance goal of 0.1 NTU or less on a consistent basis.

Since the end of March 1995, the raw water turbidity improved from that of the winter months, averaging less than 4 NTU. This improved raw water quality was again reflected in the treated water with values of filtered water averaging less than 0.2 NTU. From the end of June 1995, the treated filtered water was consistently less than 0.05 NTU. This excellent performance coincides with a number of recent changes to the plant operation. Firstly, a new laboratory turbidimeter was purchased; secondly the coagulant used was changed from alum to acidified alum (Clarion A7) and, as already discussed, the raw water quality improved significantly. Therefore, it is difficult to attribute one specific reason for the consistent high quality treated water nailed performance over the four months from June to September.

FIGURE 2 - ABC WTP - PERFORMANCE ASSESSMENT GRAPHS



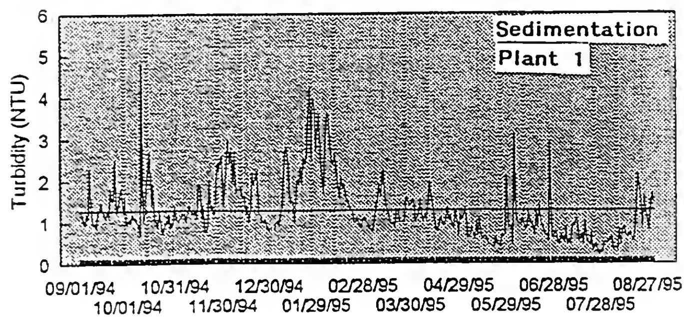
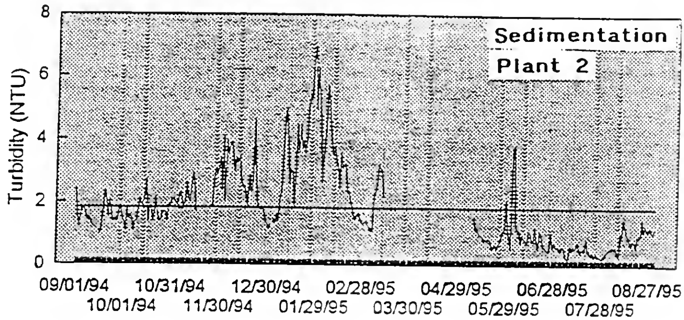
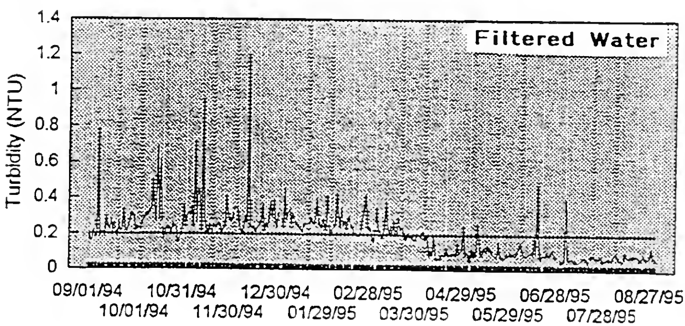


FIGURE 2 - ABC WTP - PERFORMANCE ASSESSMENT GRAPHS





A study of the turbidity output of Filter #7 was carried out during the three week period before the CPE. The filter effluent was passed through a continuous monitoring turbidimeter (Hach 1720C) and the results recorded on a circular 7-day chart. The data on the recordings indicated that a turbidity spike up to 0.35 NTU occurred immediately after each backwashing of the filter.

The week before the CPE filtered water data indicated that following backwashing the filtered water peaked to 0.15 NTU with a duration of perhaps 15 - 20 minutes before dropping below 0.1 NTU; often these peaks only reached 0.1 NTU. This represents excellent filtration operation. During this period the raw water turbidity averaged 1.3 NTU.

Prior to June 1995, the plant performance suggests that there is opportunity for performance optimization to achieve a more consistent, higher quality finished water (i.e., 0.1 NTU which minimizes public health risk) at a potentially lower operating cost.

4.0 *MAJOR UNIT PROCESS EVALUATION*

The capacities of the major unit processes were determined based on recognized design criteria. Disinfection capacity was determined based on the requirements of the USEPA's Guidance Manual[2] with respect to Giardia cyst inactivation. The capacity assessment applies the concentration - time (CT) concept for the cyst inactivation. The standard required reduction for a reasonable quality raw water source is 3 logs (99.9% removal/inactivation) and it was judged that the conventional treatment at the ABC WTP would receive a removal "credit" of 2.5 logs. This results in the requirement for the ABC WTP achieve a further 0.5 log reduction through disinfection.

Since the plant's treatment processes must provide an effective barrier at all times, a peak instantaneous operating flow (PIOF) was also determined. The PIOF represents those conditions where the treatment processes are the most vulnerable to the passage of cysts and microorganisms.

---

[2] Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems Using Surface Water Sources, USEPA, Office of Drinking Water, Washington, D.C. (1989).

If the treatment processes are adequately sized to operate at the PIOF and are within performance goals, then the major unit processes are likely capable of providing the necessary effective barriers at lower flow rates. A peak instantaneous operating flow rate of 102 ML/day was used to assess the plant's physical facilities.

The design criteria on which the estimated unit process capacities were based were as follows:

1. Flocculation
   - estimated capacity based on 20 minute Hydraulic Detention Time (HDT)

2. Sedimentation
   - estimated capacity based on 58 $m^3/m^2/d$ Surface Overflow Rate (SOR)

3. Filtration
   - estimated capacity based on 290 $m^3/m^2/d$ Hydraulic Loading Rate (HLR)

4. Disinfection
   - 3 log removal/inactivation required
   - plant 2.5 log removal credit;
   - pH 8.0
   - Temp 0.5 ^{0}C
   - Assumes 90% plug flow (0.9 X usable volume) and 1.85 m effective depth in reservoir
   - 1.5 mg/L free chlorine residual is max. allowed at clearwell outlet
   - Required CT=54.5 mg/L min. (need at least 36.3 minutes detention at the PIOF).

Unit process capability was assessed using a performance potential graph format where the estimated treatment capacity of each major unit process was compared against the current PIOF rate. The performance potential graphs prepared for the two plants are shown in Figure 3. The unit process evaluated are shown on the left side of the graphs and the various flow rates against which the processes were assessed are shown across the top.

FIGURE 3 - PERFORMANCE POTENTIAL GRAPHS

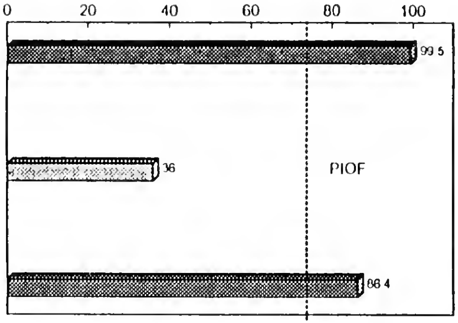
PLANT 1

UNIT PROCESS — Flow ML/d

Filtration HLR ($m^3/m^2/d$)

Sedimentation SOR ($m^3/m^2/d$)

Flocculation HDT (min.)



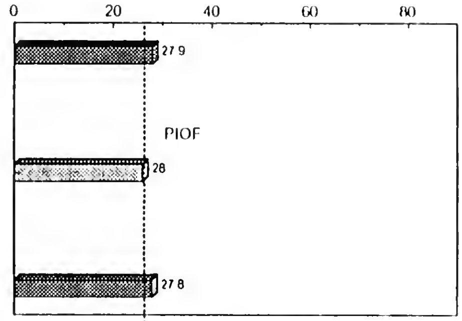
PLANT 2

UNIT PROCESS — Flow ML/d

Filtration HLR ($m^3/m^2/d$)

Sedimentation SOR $m^3/m^2/d$

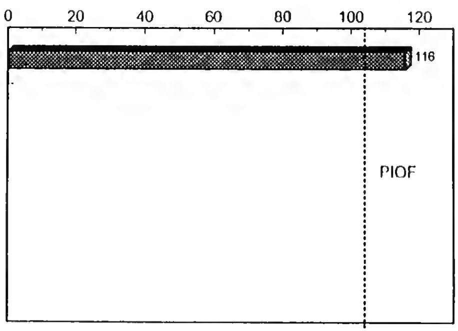
Flocculation HDT (min.)



COMBINED PLANTS DISINFECTION

UNIT PROCESS — Flow ML/d

Chlorination Contact Time (min.)



Disinfection Notes

- 3 log removal required
- Plant given 2.5 log credit
- pH 8.0
- Temp. 0.5 deg. C
- Assumes 90% plug (0.9 usable volume) flow
- & 1.85 m depth in reservoir
- 1.5 mg/L free chlorine residual
- CT=54.5 mg/L min.

Notes:

1. Flocculation - evaluated against 20 min. HDT
2. Sedimentation - evaluated against 58 $m^3/m^2/d$ SDR
3. Filtration - evaluated against 290 $m^3/m^2/d$

Horizontal bars on the graph represent the estimated peak capability of each unit process that would support achievement of desired process performance. These capabilities were estimated based on the combination of the CPE team's experience with other similar processes, industry design guidelines, and regulatory standards. The shortest bar represents the unit process which limits plant capability relative to achieving the desired plant performance.

The unit processes were assigned a rating indicated by the number at the end of the bar. Each major unit process was then categorized as indicated below:

- Type 1 - Are Adequate

  A Type 1 unit process is adequately sized. Any necessary performance improvement is most likely to be achieved through implementation of non-construction oriented follow up technical assistance.

- Type 2 - Are Marginal

- Type 3 - Are Inadequate

From the performance potential graphs, it can be seen that Plant 1, which processes 75% of the raw water flow, has adequately sized Type 1 flocculation and filtration facilities with the sedimentation unit process being about half the size theoretically needed. The 1980 plant upgrade used some of the sedimentation tankage, assuming that the plant could operate in the direct filtration mode - there is a by-pass directly from the flocculation to the filters. As a result, the Plant 1 sedimentation process was not considered to be a major performance limiting impact.

In Plant 2, which processes 25% of the raw water flow, all processes were categorized as Type 1.

The common disinfection facility was also adequate and categorized as Type 1.

A special study was carried out to determine backwash efficiency and filter media depth. The backwash rate supplied by the backwash pumps was sufficient to expand the bed by about 20% and adequately clean the bed. Filter media depth was as indicated in plant design specifications.

5.0 *PERFORMANCE LIMITING FACTORS*

The areas of design, operation, maintenance, and administration were evaluated in order to identify factors which limit performance. These evaluations were based on information obtained from the plant tour, interviews, performance and design assessments, special studies, and the judgement of the evaluation team. Each of the factors were classified as A, B, or C, according to the following guidelines:

A -- Major effect on a long-term, repetitive basis
B -- Minimal effect on a routine basis or major effect on a periodic basis
C -- Minor effect.

Of the five factors identified, three were "B" factors and two were "C's". These ratings reflect the relatively high level of performance of the plant. The "B" factors were prioritized in terms of relative importance; "C" factors are merely listed. Of the four categories evaluated, there was one "B" Factor each in the areas of administration, operations and design. Maintenance factors were not felt to impact on the plant performance.

The factors identified were prioritized as to their relative impact on performance and are summarized below:

1. Administrative Policies (B-1)

   Issues in this category were noted in several areas including:

   - The performance target or goal of 0.1 NTU is not clearly established for plant staff nor clearly communicated to them by plant management. As a result, there is no commitment from staff to ensure that this goal is consistently met.
   - There is no incentive to try to continue to improve the plant operation in terms of producing the highest quality of finished water at the lowest cost.
   - There is no procedure to ensure that new operating staff have opportunity to acquire sufficient skills from knowledgable staff before being given operating responsibility.

2. Operator Application of Concepts and Testing to Process Control - Operations (B-2)

This factor relates to the ability of operations staff to apply their water treatment knowledge to interpret process test results and adjust process conditions to support optimum performance. This factor was demonstrated in a number of ways:

- Very high quality raw water has led to complacency on the part of plant staff in terms of process control. There is little need to adjust conditions to produce a high quality finished water. As a result, technical skills such as jar testing, to respond to even small changes in raw water quality are not used. As such the capability to respond to process changes may not be adequate.
- Filtered water turbidimeters are not repaired or replaced so that the ability to optimize or even to monitor performance of this key barrier does not exist.
- The link between turbidity spikes from key unit processes, especially filtration, and potential public health impact, does not appear to be clearly understood.
- The plant staff could not discern whether low raw water turbidities, changes in coagulant or different turbidity reading from a new turbidimeter led to improved performance in June 1995.

3. Lack of Process Flexibility - Design (B-3)

There is no ability to independently control chemical feed rates to different filter's, no ability to apply a filter aid or to dose chlorine at different rates to the two plants. The fact that there are two plants with different designs make control more difficult, but at the same time more necessary. Operation of the two plants at the optimum is difficult to establish.

The final two factors are both "C" factors, those having a minor effect. Both are design factors which are not presented in any particular order.

- The sedimentation capacity is limited in Plant 1 which results in floc carryover to the filters under peak hydraulic loading;

- There is a lack of sludge treatment processing to permit routine cleaning of the sedimentation tanks which can lead to sludge accumulation and consequent solids carryover to the filters.

In developing this list of factors limiting performance, 65 potential factors were reviewed and their impact on the performance of the ABC Water Treatment Plant was assessed. These factors are outlined in the USEPA Handbook[1]. Five factors were identified, and numerous other factors were not felt to be impacting plant performance. Most notably, the administration acted in a professional manner and were genuinely committed to learning about methods to optimize existing plant performance. This type of attitude represents a solid foundation for future plant optimization activities.

6.0 *SUMMARY*

Comprehensive Technical Assistance (CTA) is a formal and comprehensive program that systematically addresses the factors identified in a CPE as limiting the plant's performance. Activities during a CTA normally focus on improving performance through the transfer of process control capabilities to the plant operators. Administrative and minor design factors are also resolved as they relate to their impact on plant performance. Typically, all changes during a CTA are implemented by local personnel under the guidance of a facilitator external to the plant staff. The facilitator can be a consultant or other qualified person.

Many of the factors identified by this CPE could be addressed by a CTA. For example, as the municipal administration moves to address the first B factor identified - in the area of administrative policies - it will be expected that the enthusiasm and tenacity to achieve the higher operational standard will positively affect the second B factor, the operator application of concepts and testing to process control.

The finished water at the ABC WTP meets Ontario drinking water objectives. The plant performance since June of 1995 suggests that there is capability for performance optimization to achieve a more consistent, higher quality finished water (i.e. ≤ 0.1 NTU, which minimizes public health risk) at a lower operating cost. This capability represents a viable and worthwhile challenge for ABC WTP staff.

APPENDIX F

Example Special Study

SPECIAL STUDY

TITLE: Reduce Plant Flow

HYPOTHESIS: A reduction in peak instantaneous operating flow will decrease finished water turbidity.

APPROACH:

1. Reduce peak instantaneous operating flow to plant to 3,000 L/min. by adjusting valve at raw water pump.

2. Relocate pressure gauge to location upstream of throttling valve.

3. Reduce chemical feed rate in proportion to flow.

4. Measurements: (One week prior to change/one week after change.)

   a. Raw water turbidity every four hours during operation.
   b. Settled water turbidity every four hours during operation.
   c. Effluent turbidity from each filter every four hours during operation.
   d. Continuous measurement of finished turbidity with existing turbidimeter.
   e. Influent water temperature on daily basis.

DURATION: One week under current conditions and one week under changed conditions. If raw water quality changes dramatically, repeat.

EXPECTED RESULTS:

1. Reduction in settled water turbidity and in variations.

2. Reduction in filter water turbidity and in variations.

3. Reduction in finished water turbidity to <0.1 NTU on continuous basis.

4. Increase in filter run time.

CONCLUSIONS: To be completed after study.

IMPLEMENTATION: To be completed after study.

APPENDIX G

Example Water Treatment Plant Operating Procedure

STANDARD OPERATING PROCEDURE

Subject: Cationic and Nonionic Polymer Feed Pumps

Purpose: To derive the approach to calibrate the cationic and nonionic polymer feed pumps.

1. Open valve on polymer pump discharge that allows polymer to be pumped to polymer solution tank.

2. Shut off valve to injection point(s).

3. Set "% of Full Stroke" on pump at 20.

4. Turn on pump.

5. Using a 1,000 mL graduated cylinder and a stopwatch, measure the amount of time it takes to fill the cylinder to at least the 300 mL mark. To simplify calculations, measure flow to the nearest minute after passing the 300 ml mark. Repeat this measurement and record both values.

6. Repeat Step 5 for "% of Full Stroke" settings of 40, 60, 80 and 100.

7. Calculate the flow in milliliters per minute by dividing the measured flow by the number of minutes. Do this for each measured flow.

8. Plot each value of "Flow in mL/min" versus "% of Full Stroke" setting on an 8-1/2"x11" sheet of graph paper (10 squares to the inch). Plot flow on the vertical axis, stroke setting on the horizontal axis. A straight line plot should result; some fitting of a "best fit" line between points may be necessary.

   (NOTE: Settings below 20 and above 80 should be avoided during operation unless the flow from the feeder is measured at that particular setting.)

APPENDIX H

Example Daily and Monthly Control Sheets for a Small Direct Filtration Plant

WATER TREATMENT PLANT - DAILY DATA SHEET

Plant Operator __________ Date ______

DAILY INFORMATION:

Target Plant Flowrate	L/min.	Cationic Polymer Tank Rdg.	cm
Raw Totalizer Reading	m^3	Cationic Polymer Used	L
Raw Volume	m^3	Liquid Alum Tank Reading	cm
Backwash Totalizer Rdg.	m^3	Liquid Alum Used	L
Backwash Volume	m^3	Hypochlorite Tank Reading	cm
Finished Volume	m^3	Sodium Hypochlorite Used	L
Hour Meter Reading	hr	Headloss Setting	m
Operating Time	hr	No. of Backwashes	#

TIME RELATED INFORMATION:

Time of Reading	___	___	___	___	___
RAW WATER					
Turbidity (NTU)	___	___	___	___	___
Temperature (deg.C)	___	___	___	___	___
pH	___	___	___	___	___
Colour (TCU)	___	___	___	___	___
Alkalinity (mg/L)	___	___	___	___	___
TREATED WATER					
Turbidity (NTU)	___	___	___	___	___
pH	___	___	___	___	___
Free Cl_2 Residual (mg/L)	___	___	___	___	___
Alkalinity	___	___	___	___	___
FILTER EFFLUENT					
No.1 Eff.Turb. (NTU)	___	___	___	___	___
No.2 Eff.Turb. (NTU)	___	___	___	___	___
No.3 Eff.Turb. (NTU)	___	___	___	___	___
No.4 Eff.Turb. (NTU)	___	___	___	___	___
CHEMICAL ADDITION					
Alum					
Dose (mg/L)	___	___	___	___	___
Pump Setting (%)	___	___	___	___	___
Feed Rate (mL/min)	___	___	___	___	___
Cationic Polymer					
Dose (mg/L)	___	___	___	___	___
Pump Setting (%)	___	___	___	___	___
Feed Rate (mL/min)	___	___	___	___	___
Chlorine					
Dose (mg/L)	___	___	___	___	___
Pump Setting (%)	___	___	___	___	___
Feed Rate (mL/min)	___	___	___	___	___

EXAMPLE MONTHLY PROCESS CONTROL DATA SHEET

Day	Plant Flowrate (L/min)	Operating Time (hr)	Raw Volume (m^3)	Backwash Volume (m^3)	Treated Volume (m^3)	Backwash Use (%)	Turbidity (NTU)								
							Raw			Filter 1			Treated		
							min	max	avg	min	max	avg	min	max	avg
1															
2															
3															
4															
5															
6															
7															
8															
9															
10															
11															
12															
13															
14															
15															
16															
17															
18															
30															
min															
max															
avg															

Day	Colour (TCU)		pH		Alkalinity (mg/L)		Temp. (°C) Raw	Free Cl_2 (mg/L) Trtd.	Chlorine Feed		Alum Feed		Polymer Feed	
	Raw	Trtd	Raw	Trtd	Raw	Trtd			Used (L)	Dose (mg/L)	Used (L)	Dose (mg/L)	Used (L)	Dose (mg/L)
1														
2														
3														
4														
5														
6														
7														
8														
9														
10														
11														
12														
13														
14														
15														
16														
17														
18														
19														
30														
min														
max														
avg														

APPENDIX I

Design-Related Performance-Limiting Factors

Identified in Actual CPEs

DESIGN-RELATED PERFORMANCE LIMITING FACTORS

The design problems listed in this appendix were identified during actual CPEs and CCPs. Each of the identified problems was felt to be directly or indirectly impacting plant performance. These problems are discussed in the context of the following categories:

Intake Structures	Filtration
Raw Water Pumps	Disinfection
Rapid Mix	Sludge/Backwash Water Handling
Flocculation	Laboratory Facilities
Sedimentation	Miscellaneous

Intake Structures/Raw Water Pumps

- Arrangement of screens allows excessive accumulation of plant material.
- Intake structure configuration allows accumulation of silt and mud.
- Intake orientation and screen location allows build-up of slush ice during winter.
- Infiltration gallery fails because of accumulation of silt.
- Constant speed, high volume pumps make plant flow control difficult.

Rapid Mix/Flocculation

- Rapid mix facilities are not provided to incorporate chemicals into plant flow.
- Mixing energy is inadequate to provide instantaneous chemical mix.
- No flocculation facilities are provided.
- Flocculation is conducted at bottom of sedimentation basin, resulting in excessive turbulence for good settling.
- Single-stage flocculation with limited detention time limits floc formation.
- Constant speed flocculation drives allow no energy adjustment.
- Lack of baffling between adjacent flocculation and sedimentation basins results in excessive turbulence that degrades sedimentation performance.

Sedimentation

- Freezing during cold weather.
- Short-circuiting due to poor inlet baffle configuration.
- Unbalanced weirs cause uneven draw-off from basin.
- Leaking weirs cause basin short-circuiting.
- Excessive surface overflow rates make solids capture difficult.
- Shallow depth limits sludge storage and promotes solids carryover.

Filtration

- Malfunctioning rate control valves cause fluctuation in filter flow rates.
- Underdrain failure disrupts media.
- Location of air backwash header beneath support gravel results in "blown" support gravels when air diffuser fails.
- Failure of filter cell dividers in an automatic backwash (travelling bridge) filter results in poor filter bed development and backwash.
- Inadequate control of backwash in an enclosed self-backwashing filter causes a severe build-up of sludge within the filter.
- Lack of surface wash and/or air scour facilities results in severe accumulation of mudballs.
- Automatic backwash control limits flexibility to extend backwash time or increase volume, resulting in an accumulation of dirt and mudballs in the filter.
- Limited water depth above filter media causes severe air binding in filters.
- Raw water turbidity too high for direct filtration.

Disinfection

- Lack of detention time in clearwell limits contact time available to meet CT requirements.

- Lack of baffling in clearwell limits contact time available to meet CT requirements.
- Uncovered treated water reservoir exposes water to contamination.
- Lack of standby chlorinator creates risk of disinfection failure.

Sludge/Backwash Water Treatment

- Return of backwash water to outlet of presedimentation basin increases turbidity load to plant.
- Return of backwash water to head of plant increases risk for passage of cysts through plant.
- Limited capacity of backwash storage places a ceiling on backwash duration.
- Limited sludge storage capacity potentially limits capability of sedimentation.

Laboratory Facilities

- Not provided.
- Inadequately equipped.
- Poorly lit and unheated.
- Insufficient floor and bench space.

Chemical Feed Facilities

- No facilities available to feed coagulant or filter aid chemicals.
- Oversized feeders provide innaccurate feed rate at low flows.
- No flexibility to feed chemicals at points other than rapid mix.
- No flexibility to feed stabilization chemicals (eg. lime, soda ash, etc.) at a location (eg. after filters) away from the alum feed.
- Poor measuring and mixing equipment available to make polymer dilutions.
- Polymers being fed at rapid mix, resulting in shearing of polymer chains and ineffectiveness of product.

Miscellaneous

- No flow splitting capability to parallel units.
- Individual process trains requires operation of two treatment plants rather than just one.
- Flow measurement inaccurate because of upstream turbulence.
- Lack of flow recording equipment.
- Finished water flow measurement inaccurate because all water flow is not directed through meter.
- No sample taps on filter effluents.
- No sample taps on sludge lines or raw water line.
- Automatic operation of plant resulting in numerous start-ups daily of dirty filters.
- No standby equipment for critical pieces of equipment such as backwash pumps, chlorinators, coagulant feeders.
- No alarm system for raw or treated water turbidity at plants that are not staffed at all times plant is in operation.
- No continuous recording turbidimeters on individual filter effluents.

APPENDIX J

Chemical Feed Calculations

CHEMICAL FEED CALCULATIONS

Chemicals such as coagulants, coagulants aids and filter aids must be used in water treatment to effectively remove colloidal particles from the water. To use them properly, it is necessary to understand the calculations necessary to prepare stock solutions to be used in jar testing, to determine how much stock solution must be added to each jar, and to determine the required feed rates in the plant. These calculations are explained in the following paragraphs for alum; the calculations can also be applied to other chemicals such as polyaluminum chloride, iron salts, and polymers.

ALUM STOCK SOLUTIONS

When conducting a jar test to determine the optimum alum dosage, it is necessary to add varying amounts of alum to the jars. Since the bulk liquid alum is very concentrated it is necessary to prepare a diluted stock solution. For example, if the stock solution is made up to a concentration of 10,000 mg/L (10 mg/mL), adding 1 mL of stock solution will add 10 mg of alum to the jar. If the test jar contains 1 L, the resulting dosage will be 10 mg/L. Likewise, adding 2 mL to a 1 L test jar will provide a dosage of 20 mg/L, etc. The procedures for making stock solutions from liquid and dry alum are presented below.

Stock Solution From Liquid Alum For Jar Testing

1. Determine the density of liquid alum by reviewing the shipment information provided by the supplier, or by weighing a known volume of sample. For example, if the mass of a 10 mL sample is 13.5 g, then the density of the liquid alum sample = 13.5 g per 10 mL = 1.35 g/mL.

2. Determine the concentration of liquid alum by reviewing the supplier information. For example, the information reveals the liquid alum being delivered is 48.5 % dry alum equivalent.

3. Select the concentration of the stock solution that you wish to use, which can be expressed as a weight per unit volume (mg/L) solution. If a weak stock solution is used, then a large amount of solution will have to be added to jars. Conversely, a strong stock solution must be added in small amounts, which increases the chance for errors in dosing jars. MOE staff have found that a 10,000 mg/L concentration works best for all chemicals except polymers, which should be prepared as a 1,000 mg/L solution.

4. Prepare the stock solution by the volumetric solution method.

Conc. of liquid alum on a dry weight basis (from above) = 48.5% = 0.485 g of dry alum/g of liquid alum

Density of liquid alum (above) = 1.35 g of liquid alum/mL of liquid alum

Assume a 10,000 mg/L stock solution is desired. The amount of bulk liquid alum that is needed to prepare 1 L of stock solution may be calculated by using the relationship below.

Into 1 L of water, add 10,000 mg dry alum

$$= 10 \text{ g dry alum}$$

$$= 10 \text{ g}_{dry} \times (1 \text{ g}_{liq} / 0.485 \text{ g}_{dry})$$

$$= 20.6 \text{ g}_{liq}$$

Into 1 L of water, volume of liquid alum needed

$$= \text{mass / density}$$

$$= 20.6 \text{ g}_{liq} \times (1 \text{ mL}_{liq} / 1.35 \text{ g}_{liq})$$

$$= 15.3 \text{ mL}_{liq}$$

Therefore, the alum stock solution is made up by placing 15.3 mL of bulk liquid alum into a 1,000 mL flask and filling the flask with water to the 1,000 mL mark.

NOTE: When preparing stock solutions, the water used to dilute the chemical should be the same as in actual plant conditions. For example, if alum is diluted with plant treated water prior to application, plant treated water should be used to prepare stock solutions. If alum is fed neat (i.e. undiluted), stock solutions should be prepared with distilled or demineralized water.

Stock Solution From Dry Alum for Jar Testing

An alum stock solution may be made using dry alum by following the procedure below.

1. Select the desired concentration of alum stock solution (see Item 3 above).

2. The weight of dry alum that must be added to prepare 1 L of 10,000 mg/L stock solution may be calculated by using the relationship below.

   $m = CV$

   where, m = mass of dry alum required
   C = desired stock solution concentration
   V = desired volume of stock solution to be produced

   Therefore:

   $m = 10{,}000 \text{ mg/L} \times 1 \text{ L} = 10{,}000 \text{ mg} = 10 \text{ g}$

Therefore, the 10,000 mg/L alum stock solution is made up by placing 10 g of dry alum into a 1,000 mL flask and filling the flask with water to the 1,000 mL mark.

JAR TEST CALCULATION

Once a stock solution has been prepared, it is necessary to calculate the amount of stock solution to add to each jar to achieve a desired dosage. The following equation is used to determine this amount.

$$\text{Volume of Stock Soln. Added to Jar (L)} = \frac{\text{Jar Volume (L)} \times \text{Desired Dosage (mg/L)}}{\text{Stock Soln. Conc. (mg/L)}}$$

For example, if an operator wanted to test a 45 mg/L dosage of alum and was using a 10,000 mg/L stock solution and 1 L jars, then:

$$\begin{aligned}\text{Volume of Stock Solution to be Added to the Jar} &= (1 \text{ L} \times 45 \text{ mg/L})/10{,}000 \text{ mg/L} \\ &= 45 \text{ mg}/10{,}000 \text{ mg/L} \\ &= 0.0045 \text{ L} \\ &= 4.5 \text{ mL}\end{aligned}$$

TREATMENT PLANT FEED RATE CALCULATION

The desired alum dose should be determined by jar testing, or other means. Once the dose is determined, calculations must be done to set the chemical feed pumps.

Liquid Alum Feeders:

The chemical feed rate can be calculated as shown below.

$$\text{Chemical Feed Rate (L/min)} = \frac{\text{Plant Flowrate (L/min) x Desired Dosage (mg/L)}}{\text{Liquid Alum Conc. (mg/L)}}$$

Example:

Plant flow = 5 MIGD
Alum dosage = 25 mg/L
Liquid alum is fed undiluted

Then:

Concentration of liquid alum on a Weight per Volume Basis $= 0.485\ g_{dry}/g_{liq} * 1.35\ g_{liq}/mL_{liq}$

$= 0.655\ g_{dry}/mL_{liq} = 655{,}000$ mg/L

Plant Flow = 5,000,000 IG/d x 4.54 L/IG x d/24 h x h/60 min = 15,764 L/min

Therefore:

$$\text{Chemical Feed Rate} = \frac{15{,}764 \text{ L/min x } 25 \text{ mg/L}}{655{,}000 \text{ mg/L}} = 0.6 \text{ L/min} = 600 \text{ mL/min}$$

Using feed pump calibration curve, set pump frequency and stroke to feed at 600 mL/min.

Dry Alum Feeders:

The chemical feed rate can be calculated as shown below.

Chemical Feed Rate (mg/min) = Plant Flowrate (L/min) x Desired Dosage (mg/L)

Using above example:

Chemical Feed Rate = 15,764 L/min * 25 mg/L = 394,100 mg/min = 0.394 kg/min = 23.6 kg/h

Go to the feeder calibration curve and determine what feed setting is required to feed 23.6 kg/h. Dial the feeder control to the appropriate setting.

APPENDIX K

Example CTA Summary Report

SUMMARY REPORT
WATER TREATMENT PLANT X

COMPREHENSIVE TECHNICAL ASSISTANCE

CONTENTS

FIGURES

Note: This report was written for a CTA conducted at a U.S. water plant in the early 1990s, hence the reference to the Surface Water Treatment Rule.

INTRODUCTION

The CCP approach is a proven procedure for improving performance of water treatment plants. This approach consists of two components, the CPE phase and the CTA phase. A CPE is a thorough review and analysis of a plant's design capabilities and associated administrative, operation, and maintenance practices. It is conducted to identify factors that may be adversely impacting a plant's capability to achieve optimal performance. Its major objective is to determine if significant improvements in performance can be achieved without major capital improvements. A CTA is a performance improvement phase that may be implemented if results from the CPE indicate that improved performance can be achieved. During the CTA phase, factors identified by the CPE are systematically eliminated. The major benefit of a CTA is that it optimizes the capability of existing facilities without the expense of major capital improvements.

A CPE was conducted at plant X on August 21-24. It revealed that the plant had some performance problems and that the top ranked factors identified were process control related. It was felt that operator training, conducted as a portion of a CTA, would improve plant performance. This report summarizes the results of the CTA, which was initiated in the following April.

CPE RESULTS

A CPE was conducted August 21-24 at water treatment plant X. The plant is a direct filtration facility constructed in 1978. Treatment includes coagulant chemical feed (alum and cationic polymer), flocculation in a reaction basin, nonionic polymer filter aid feed, filtration through four dual media filters, post chlorination, and gravity flow from the plant to storage and distribution. Raw water is supplied from a multiple use lake located several miles northwest of the plant. Raw water quality is generally good in winter months, with turbidities in the 5 to 10 NTU range; but prevailing westerly winds often stir up sediments in the relatively shallow lake in other seasons, resulting in peak raw water turbidities as high as 50 to 280 NTU.

A review of operating data for the previous year revealed that the plant was generally producing water of less than 1.0 NTU, but would not meet the Surface Water Treatment Rule (SWTR) (1) requirements of 0.5 NTU 95 percent of the time. Further performance evaluation included a special study to determine the turbidities before and after backwashing. Results indicated that filter effluent turbidities increased to 3.2 NTU and did not drop below 1.0 NTU for over two hours. Optimum performance would be a 0.2 NTU increase for less than 10 minutes and a return to operating turbidities of less than 0.1 NTU.

A performance potential graph projected that the design-rated 11,400 m^3/d facility would have to be de-rated to 5,700 m^3/d because of a severe air binding problem identified with the filters. This problem was exacerbated by the design of the filter effluent header, which allowed the formation of negative pressure in the filter underdrains. A short detention time in the reactor/flocculation basin also resulted in a projected capacity less than design for this unit process. A longer time was felt to be necessary because of the longer reaction time needed with cold water during winter operation.

The plant's performance limiting factors were assessed and prioritized in order of significance as follows:

1. Operator Application of Concepts and Testing to Process Control - Operation

   The plant had no formal process control program to provide information from which operational decisions could be made. Although the operators had a good understanding of water treatment, they were not applying their knowledge to operation of the plant. Because of the highly variable raw water quality it was essential that the plant be monitored continuously and coagulant dosages changed to maintain a consistent high quality finished water.

2. Process Control Testing - Operation

   The lack of process control testing resulted in insufficient data being collected to properly assess plant performance (e.g. jar testing was not being conducted to optimize the coagulation process).

3. Filtration - Design

   Turbidity measurements taken at the time of the evaluation demonstrated that the filters were not performing optimally. The presence of filter media in the clearwell was an indication that the filters may have been damaged by backwashing or the release of air from the severely air-bound filters. More involved evaluations were felt to be necessary to determine if the support gravels were damaged. Filter capacity was also being affected by air binding and periodic high raw water turbidities, necessitating frequent backwashing.

4. Raw Water Turbidity - Design

   The turbidity of the raw water often exceeded that normally recommended for the direct filtration process. During periods of high turbidity it was projected that it would be necessary to reduce plant flow rates to produce an acceptable water.

5. Plant Coverage - Administration

The plant was not attended on weekends and the operators were often conducting other duties away from the plant during weekdays. It was assessed that this practice would result in undetected periods of poor finished water quality.

6. Lack of Standby Units - Design

There were no standby alum and polymer feed pumps. Failure of one of the units would result in poor plant performance.

7. Reactor/Flocculation Basin - Design

The reactor basin was too small to provide adequate time for flocculation during cold water conditions in winter months. It was projected that the plant flow rate would have to be reduced during winter to ensure adequate flocculation.

8. Plant Inoperability Due to Weather - Design

Drought severely impacted the availability of water from the lake in 1985. An engineering study had been completed to assess relocation of the intake to a deeper part of the lake.

The CPE report recommended that a follow-up CTA be conducted because the top ranked factors identified were process control related and it was felt that operator training would improve plant performance. Also, since the historical peak day demand was only about 5,700 m^3, it was concluded that the plant could be operated at a lower flowrate for a longer period to address the design-related limitations of the filters and reactor/flocculation basin.

CTA SIGNIFICANT EVENTS

The CTA was initiated in the following April. Major activities are briefly summarized below.

Consultant Initial Site Visit (April 3-6)

- Implemented a process control sampling and testing schedule and developed a daily data sheet to record results.
- Implemented policies/procedures approach.
  - Developed procedures for calibrating chemical feeders and calculating chemical dosages so that chemicals could be accurately applied.

- Developed procedures for calibrating effluent turbidimeter.

- Developed procedure for process control testing and sampling.

- Initiated a special study to determine the effect of operating the plant at a reduced flow rate and operating the filters without a negative pressure. At the conclusion of the visit, the plant was operated at 4,000 L/min. (~5,700 m^3/d) rather than at 7,900 L/min. (~11,400 m^3/d) and a plug was removed from the filter effluent header to allow the negative pressure to be released from the filter.

- Identified special studies to be conducted in the future including: analysis of dissolved oxygen and temperature in raw water including transmission line to determine cause of filter air binding, evaluation of effect of rapid mix on coagulant feed, and analysis of effect of alum and polymer feed points.

- Developed action/implementation plan and made assignments to the operating staff and administrators with due dates to ensure activity continued until next site visit.

- Chemical feed rates were not changed during the visit because it was desirable to have the plant staff operate the plant following feeder calibration to evaluate plant performance with the newly calculated dosages.

Evaluation Period (April - July)

- Continued process control testing on plant as presented in sampling and testing schedule procedure.

- Operated plant at reduced flow rate (4,000 L/min.) and without negative pressure on filter effluent header.

- Initiated weekly transmission of data to consultant and initiated weekly phone calls between plant staff and consultant.

- Consultant developed computer spreadsheet to analyze plant data.

- Installed accurate pressure gauges on lake intake pumps to relate pump discharge pressure to pump output.

- Sent finished water turbidimeter to factory service center for repair.

- Plant staff modified daily data sheet based on operating experience.

- Purchased dissolved oxygen meter for special study on filter air binding.

- Welded sample taps and chemical feed taps on plant influent line before and after orifice plate in preparation for chemical feed special study. The plant staff hired a local welder to make the welds.

Consultant Site Visit (June 26 - 27)

- Conducted jar tests using filter paper and established new chemical feed rates for the alum and cationic polymer. Plant performance improved dramatically prior to the end of the site visit.

- Developed a procedure for jar testing using filter paper to correlate results with plant performance. Explained the conduct and interpretation of the jar test/filter paper procedure to the operating staff.

- Expanded process control program to include jar testing/filter paper testing to establish chemical feed rates.

- Reviewed chemical feed calculations with plant staff.

- Investigated filter backwash and determined that additional wash time would be required to adequately clean the filters.

- Updated the special study on relocation of alum and cationic feed points.

- Updated the action-implementation plan.

Evaluation Period (July - October)

- Implemented full plant process control program including evaluating raw water quality and determining the correct coagulant and filter aid feed rates. Jar tests were used to determine required chemical doses when raw water quality changed.

- Continued weekly transmission of data to consultant and weekly phone calls between plant staff and consultant.

- Consultant developed monthly data sheet to analyze plant data.

- Relocated the feed points for alum and cationic polymer addition to take advantage of a hydraulic flash mix at the orifice plate located in the influent piping. Completed special study on relocation of the chemical feed points.

- Convinced administrators to allow time for the operating staff to remain at the plant to conduct process control testing and to make plant adjustments.

- Purchased additional laboratory supplies for conducting jar tests.
- Extended filter backwash time to allow more complete cleaning of filters.
- Staff investigated cost of monitoring raw water quality with a turbidimeter and alarm at raw water pumping station, an alarm on the existing turbidimeter at the plant, and a streaming current monitor with automatic control of coagulant feeders.

Consultant Site Visit (October 17 - 19)

- Reviewed process control program.
- Conducted jar tests to evaluate alum replacement products.
- Reviewed chemical feed calculations.
- Completed CTA assistance.

CTA RESULTS

Significant improvement in plant performance was achieved during the conduct of the CTA. This is depicted graphically in Figure 1. It is noted that while plant operation improved after reducing the plant flow rate and eliminating the negative pressure on the filters in April, performance remained erratic until process control, including chemical adjustments, was implemented in July. After July, plant finished water turbidities remained very consistent at about 0.1 to 0.2 NTU through the duration of the project. This consistent performance was achieved even though raw water turbidities, shown in Figure 2, varied widely. Plant finished water quality remained below 0.3 NTU even when the raw water turbidities reached 70 NTU because the operating staff consistently monitored varying raw water quality and responded by changing chemical feed rates. The plant performance is especially impressive since influent turbidities frequently exceeded values thought to be treatable with direct filtration (e.g., >50 NTU). Another indication of improved performance was that filter effluent turbidity following a backwash did not exceed 0.3 NTU and returned to 0.15 NTU within minutes after the wash.

The improved performance was achieved primarily through improved process control activities and lowering plant loadings that were more in line with unit process capability. The primary process control tool utilized was the jar test, which proved to be valuable in allowing the operators to predict chemical doses required when raw water quality varied. The jar test was used in conjunction with filter paper to correlate results with the direct filter plant conditions. The test provided a very accurate indication of required chemical dose.

Figure 1. Finished Water Turbidities for Plant X

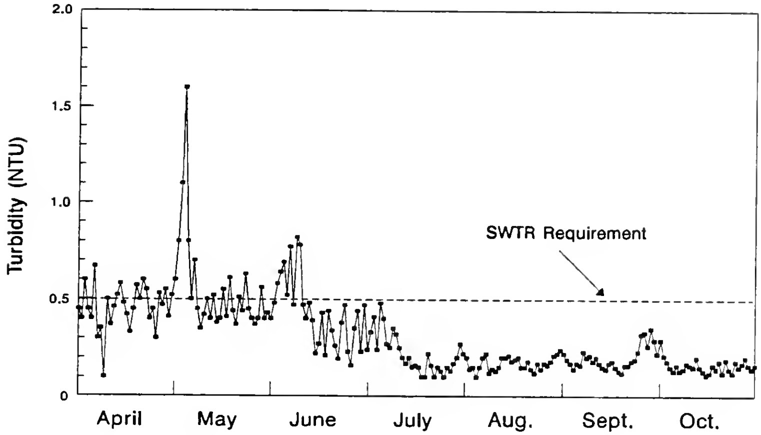
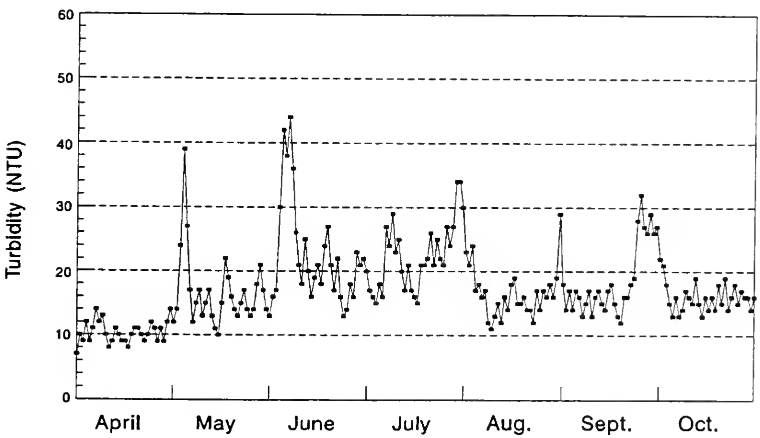


Figure 2. Raw Water Turbidities for Plant X



The plant staff became very adept at evaluating raw water quality and adjusting chemical feed rates to produce a high quality finished water on a continuous basis. The staff exhibited a great deal of expertise and professionalism during the CTA, and quickly learned chemical feed calculations and implemented the necessary process control activities.

The process control activities took additional operator time at the plant. Prior to the CTA, operators would check the plant daily; however, during the CTA, operators were at the plant a minimum of four hours each day. If plant raw water quality was changing rapidly operators would be at the plant making adjustments whenever the plant was operating. Administrators had to be convinced that the additional time was necessary to achieve and maintain improved plant performance.

Only minor physical plant modifications were required to improve plant performance. The modifications included removing a threaded plug from the filter effluent header to relieve negative pressure on the filters, and adding additional alum and cationic feed points prior to an orifice which was used as a flash mix. All minor modifications were made by the plant staff.

The administrators were favourably impressed by the level of performance achieved by the plant. Major plant (e.g. construction of a sedimentation basin) and raw water intake modifications were being planned prior to the successful implementation of the CTA. These major modifications were placed on hold based on the ability of the plant to perform within the SWTR requirements. The intake modifications may eventually be made because they will potentially reduce the turbidity load (e.g. draw water from deeper points in the lake) to the direct filtration plant allowing it to operate at higher hydraulic loading rates.

CONCLUSIONS

Implementation of a CTA at water treatment plant X was highly successful. The CTA proved that the plant could achieve compliance with SWTR turbidity requirements without major capital improvements. City administrators had planned on spending an estimated one million dollars on construction of sedimentation basin facilities and related improvements. After the CTA they decided to delay any construction until water demands required the plant to be operated at higher rates. The plant staff developed increased confidence that excellent quality water could be produced despite high raw water turbidities, and they developed a level of pride that did not allow them to accept marginal finished water quality. In addition, the jar test/filter paper procedure proved to be a valuable process control tool that allowed accurate selection of coagulant doses.
The City will have to continue the commitment to water treatment in order to sustain the level of performance obtained during the CTA. Continued production of high quality water

will require a commitment to allowing adequate operator time at the plant to make necessary chemical feed adjustments. If operators are not at the plant whenever it is operating, a turbidimeter with alarm should be installed at the raw water pumps to give the operators continuous notice of raw water changes. The use of a streaming current monitor that would automatically adjust the alum feed rate if raw water quality changes could be investigated.

REFERENCES

1. "Surface Water Treatment Rule" from Federal Register, Vol. 54, No. 124, U.S. Environmental Protection Agency, 40 CFR, Parts 141 and 142, Rules and Regulations, Filtration/Disinfection (June 1989).